Scientific and Industrial Research Council of Alberta, Report No. 18

The Bituminous Sands of Alberta

BY

K. A. CLARK and S. M. BLAIR

PART I.—OCCURRENCE

PART II.—SEPARATION OF BITUMEN FROM SAND (In preparation)

PART III.—UTILIZATION (In preparation)

PUBLISHED BY AUTHORITY OF THE HON. J. E. BROWNLEE
Chairman of the Scientific & Industrial Research Council of Alberta.

EDMONTON:
PRINTED BY W. D. McLEAN, ACTING KING'S PRINTER
1927

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ROAD MATERIALS DIVISION

PART I.—OCCURRENCE

Studied with Respect to Commercial Development

ORGANIZATION

The Scientific and Industrial Research Council of Alberta, formed in January, 1921, carries on its work in co-operation with the University of Alberta.

The personnel of the Council at the present time is as follows:

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R. M. Young, Canmore, Alberta.

Edgar Stansfield, Honorary Secretary, Industrial Research Department, University of Alberta.

Requests for information and reports should be addressed to the Honorary Secretary, Industrial Research Department, University of Alberta, Edmonton.

LETTER OF TRANSMITTAL

HONOURABLE J. E. BROWNLEE,
Premier of Alberta,
Edmonton, Alberta.

SIR:—

I have the honour to transmit herewith a report entitled "The Bituminous Sands of Alberta," Part I, prepared in co-operation with Mr. S. M. Blair.

The Scientific and Industrial Research Council instructed me to compile the results of our work to date on the bituminous sands for publication. This report deals with the occurrence of the bituminous sands in Northern Alberta and contains the results of our field examination of the deposit. Reports dealing with studies of a method for separating the bitumen from the bituminous sands and with the use of bituminous sands and separated bitumen for road construction are being prepared.

Respectfully submitted,

K. A. CLARK,
Research Engineer, Road Materials.

Department of Industrial Research,
University of Alberta,
Edmonton.

May 14, 1927.

PREFACE

The commercial development of the bituminous sands in Northern Alberta concerns the Province of Alberta more closely than it concerns any other part of the Dominion. For this reason it was natural that an investigation of the bituminous sands was included as a major item of the program of the Scientific and Industrial Research Council of Alberta. Work was begun in 1920 and progress reported from year to year in the Annual Reports of the Council. This report covers the principal results obtained to date. For convenience it has been divided into three parts, in logical order for presentation. Part I (the present volume) covers the occurrence of the bituminous sands, their accessibility, variability and other economic features. Part II (in preparation) will cover the development and operation of a commercial process for separating the bitumen from the sand. Part III (also in preparation) will cover the utilization of the bituminous sand and derived products, with principal reference to road construction.

In the actual investigations the different problems were not attacked in the order given above. Since an effective and cheap method for the separation of the bitumen from the bituminous sands appeared to be most important, this was given first consideration. The cost of transporting sand, as well as bitumen, in the raw sands, and the restricted range of use to which this crude material could be put, made it seem inevitable that any extensive development would be dependent on separation of the bitumen prior to shipment. A commercial separation process was lacking and could be provided only by technical research. The well known but heretofore inefficient method of hot water separation was studied and developed to give very satisfactory results. The study of the fundamental nature of the various operations is still in progress, and it is expected that this will result in even greater efficiency of operation.

Three main possibilities for the utilization of the bituminous sands have been considered: first, utilization of raw sands for pavements and kindred objects; second, utilization of separated bitumen in road construction; third, utilization of the bitumen as a source of petroleum products. Because of the economic conditions within the province and the many other possible sources of petroleum products, the second of these appeared to be of most immediate significance. Since road construction in Alberta must of necessity be conducted on modest lines, the use of the separated bitumen as a stabilizer for earth roads was investigated. When the separation investigation was developed to a semi-commercial scale and a fairly large quantity of bitumen became available, this was used in actual road construction. While the results obtained in these experiments were not all that were hoped for, positive stabilizing action was obtained under very difficult soil conditions. It is planned to continue these studies, keeping in touch with the advancements in road construction that are taking place in the province. Some work has also been done regarding the use of the raw sands in road construction, and the use of the bitumen as a source of petroleum products.

The bituminous sand deposits were also studied when the development of the separation process made this necessary. This work was planned to supplement the work of the Mines Branch of the Department of Mines at Ottawa, which has sent parties into the area almost yearly since 1913. Study was made of lateral and vertical variability of the deposits, with special reference to economic developments. Samples were collected from many different localities and their amenability to the separation process demonstrated. These field studies constitute Part I of the present report.

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The Bituminous Sands of Alberta

By

K. A. CLARK and S. M. BLAIR

CHAPTER I.

GENERAL INTRODUCTION

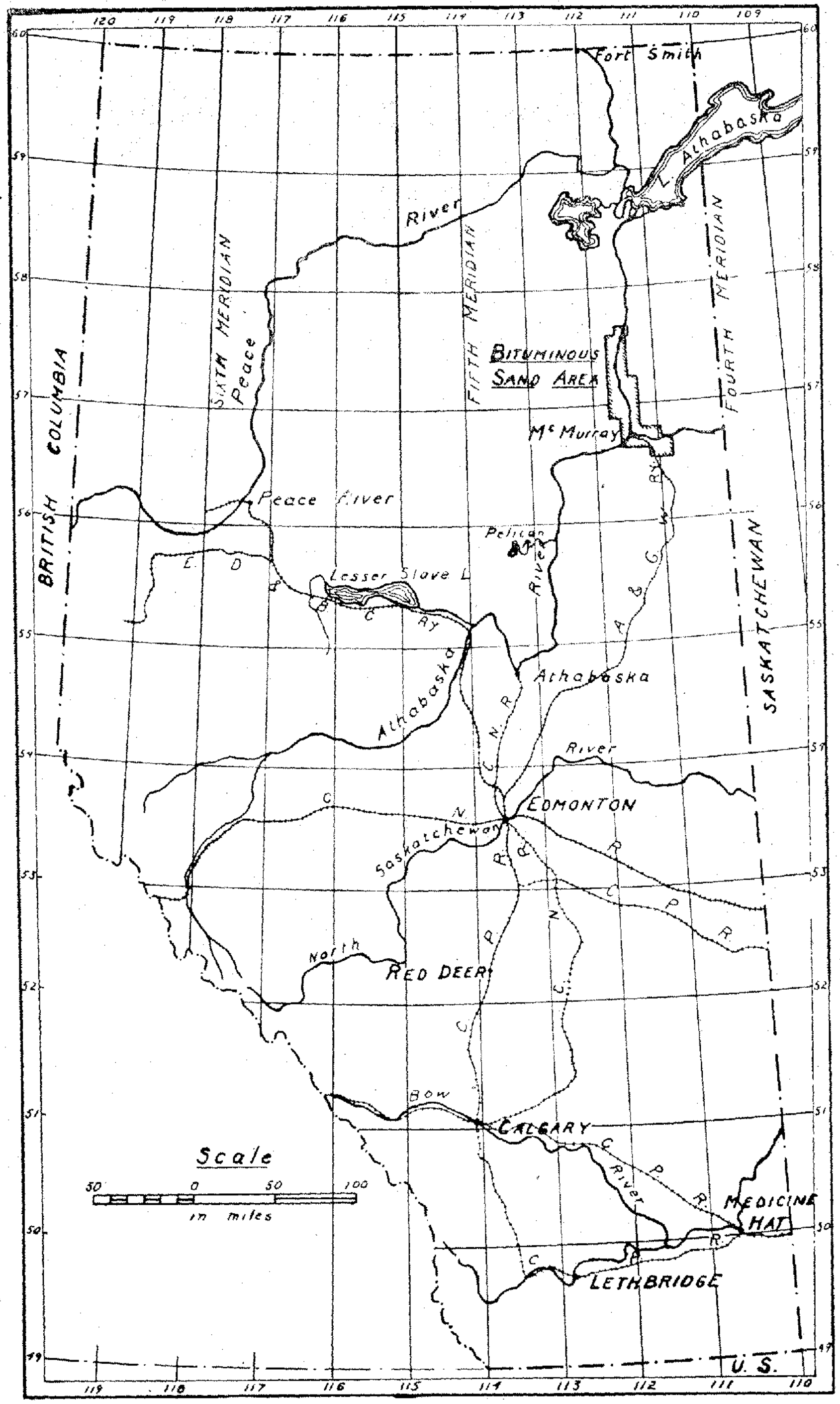
THE AREA AND ITS HISTORY

The Bituminous Sand Country.

Any traveller in Northern Alberta sees many interesting things, but none so likely to interest him, or to stimulate his imagination, as the great cliffs and slopes of bituminous sand along the banks of the Athabaska river. These exposures, some of them over 200 feet high, are found for a distance of one hundred miles along the river, and for a considerable distance up its tributary streams. The minimum area which the actual exposures indicate as certainly underlain by bituminous sand is from 750 to 1,000 square miles. There is considerable evidence to support the belief that the actual extent of the bituminous formation is much greater.[1] The deposit is the largest known body of bituminous sand.

The bituminous sand area is reached by a journey of approximately three hundred miles north of Edmonton on the Alberta and Great Waterways Railway. The terminal station of this railway is Waterways, which is located on the Clearwater river, a few miles from the town of McMurray. McMurray is at the junction of the Clearwater and Athabaska rivers. The country along the Alberta and Great Waterways Railway is a fairly well settled agricultural country as far as Lac La Biche, approximately half of the distance to Waterways. The country traversed by the railway north of Lac La Biche is principally muskeg with jackpine ridges. McMurray is a town of approximately two hundred inhabitants. It has grown up around the Hudson's Bay Company post of Fort McMurray and has become the frontier town for the fur trading and other activities of the Athabaska, Slave and Mackenzie rivers. Flat bottomed, stern wheel steamers ply the Athabaska river from McMurray to Athabaska lake and on down the Slave river to the Northern boundary of the province of Alberta at Fitzgerald, a distance of about three hundred miles. A series of rapids stops navigation here. A wagon road sixteen miles in length connects Fitzgerald with Fort Smith. Freight and passenger boats run on Slave river, Great Slave lake and Mackenzie river, between Fort Smith and the Arctic ocean. McMurray is, therefore, at the head of a waterway that leads through Northern Alberta and the North West Territories. The bituminous sand

[1] First Annual Report on The Mineral Resources of Alberta, J. A. Allan, 1920, p. 8. Dr. Allan states that at least 10,000 squares miles are underlain by the bituminous sand formation.



MAP No. 1—Map of the Province of Alberta Showing Location of the Bituminous Sand Area in Relation to the Principal Centres of Population.

country is traversed by the southern end of this great water thoroughfare.

The bituminous sand formation is the conspicuous feature of the country first passed through on the journey from McMurray down the Athabaska river. For sixty-five miles bituminous sand exposures can be seen along the river bank from the steamer deck at almost any time. For the first part of the way, the dark, imposing outcrops rise to a height of as much as two hundred and twenty-five feet. Above these, the sides of the valley rise more gradually for several hundred feet to the level of the surrounding country. Further down the river, the valley broadens and flattens out, the bituminous sand exposures become less high and finally disappear.

A number of tributary streams enter the Athabaska river within the bituminous sand area, and exposures are found in their valleys also. The exposures along these tributary streams decrease in height up stream until finally the bed of the stream lies above the formation. Their valleys are much narrower than that of the Athabaska river.

The country in which the bituminous sand occurs is well wooded with poplar, spruce and jackpine. Back from the river valley the drainage is poor and a large proportion of the country is muskeg.

The Bituminous Sand Formation.

The bituminous formation, in all probability, has a much greater extent than the 750 to 1,000 square miles in which outcrops occur. But it is only in this area, where rivers have cut valleys through overlying material and down into or through the bituminous sand, that the formation can be seen.

The bituminous sand rests on Devonian limestone. This limestone can be seen in the frontispiece, just above the river level and below the bituminous sand cliffs. The bituminous sand formation, where it can be seen, consists of a thickness of from one to two hundred feet of lenticular beds of sandy and clayey material, more or less impregnated with bitumen. Variation in the degree of impregnation is connected, as might be expected, with the nature of the mineral matter with which the bitumen is associated. Along the Athabaska river upstream from McMurray, the bituminous sand is covered by cretaceous sandstones and shales. Below McMurray such consolidated beds do not appear. Presumably they have been eroded away, and the bituminous sand now rests under a cover of loose drift, which varies in depth from several hundred to less than fifty feet in thickness.

The original source of the bitumen in the bituminous sand formation remains somewhat of a mystery. The first geologists to examine the formation held the view that the bitumen was derived from the underlying Devonian limestone. At the present time opinions are more uncertain regarding the origin of the bitumen. No evidence that the underlying Devonian limestone contains petroleum has come to light, and there are not sufficient data upon which to construct an alternative theory.

The Bituminous Sands.

The general character of the bituminous sands can be seen by an inspection of an exposure. One of those along a tributary stream is preferable for examination because constant water erosion at the base of the exposures in the narrow valleys keeps an exposed face of comparatively fresh bituminous sand. A pronounced asphaltic smell is given off from the exposed beds. The bituminous sand in the face is dark brown to black in color. Little streaks of bitumen can be seen on some sections of the face where small quantities have come to the surface and slowly worked down. The bedding of the formation is apparent. Strata thickening or pinching out laterally can be seen, as well as irregular and cross bedding. The beds of richly impregnated sands stand out in bold cliffs, while lean beds and layers of silt and clay form gentler slopes, and are less easily distinguishable.

The bituminous sand in well impregnated beds is a very compact material. The surface can be picked into easily with a sharp pointed tool, but a heavy blow makes a surprisingly small impression. If a lump is removed, it is found to be soft, in the sense that it yields to pressure and breaks down into a disintegrated mass. Close inspection shows that it is composed of an aggregation of fine sand particles, each of which is enveloped by a film of a soft, sticky bitumen. The sand is composed essentially of quartz with relatively small quantities of mica and other minerals.

Historical Review.

The bituminous sand formation was noted as one of the conspicuous features of the north country by the first white men that traversed it. Such men as Peter Pond, Alexander Mackenzie and David Thompson no doubt camped beside the same bituminous sand exposures that we see today, used the bitumen from the seepages to mend their boats and tramped over the bituminous sand taluses as they tracked their canoes back up the Athabaska river.

Peter Pond opened the first chapter of the history of Northern Alberta when, in 1788, he crossed Methy Portage, descended the Clearwater river, passed by the bituminous sand cliffs on Athabaska river and established his post, "Old Establishment" at Pond's Point, 30 miles from Athabaska lake.[2] Alexander Mackenzie came to the Athabaska a few years later. He makes special reference to the bitumen seepages and to the boatmen heating the bitumen with spruce gum to compound a boat-mending material.[3] David Thompson made a survey of Athabaska river from the Clearwater river to Athabaska lake in 1803. Within the next fifty years many of the Arctic explorers, including Franklin, Richardson, Simpson and Back, passed through the bituminous sand country.

Prof. John Macoun[4] was the first member of the Geological Survey of Canada to travel the Athabaska river and to record the

[2]R. G. McConnell in his report Geological Survey of Canada, Vol. V. 1890-91, Sec. D, gives a brief history of the Athabaska Country.

[3]Journeys on the North American Continent from the Atlantic to the Pacific, 1789-93. Sir Alexander Mackenzie.

[4]Geological and Topographical Notes by Prof. Macoun on the Lower Peace and Athabaska Rivers. Geological Survey of Canada, 1875-76, p. 87.

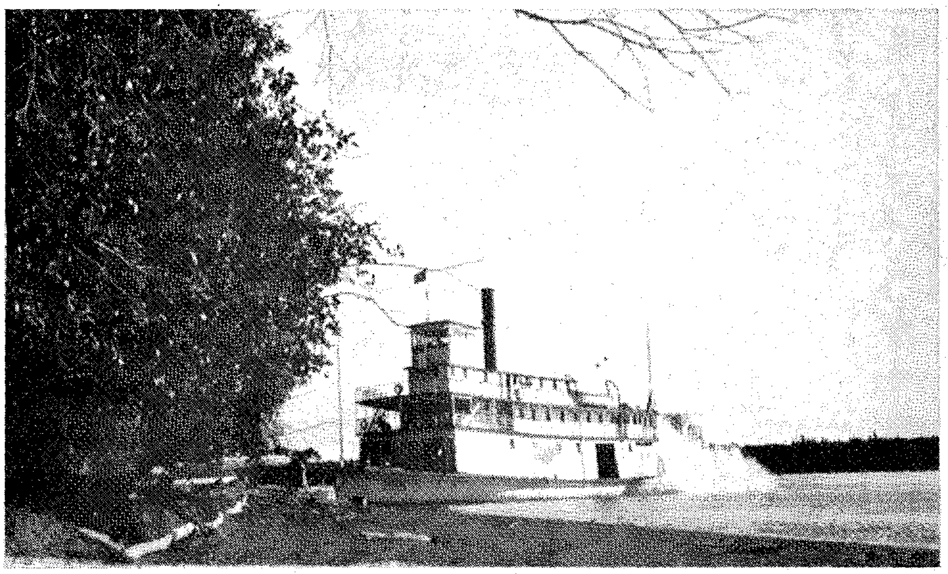


PLATE II.—Transportation on the Athabaska River. The S.S. Athabasca River Landing Freight.

bituminous sands in geological reports. He comments in his 1875 report on the tar conglomerates, the oil shales and the tar springs which he observed on his journey up the Athabaska river. He mentions particularly the high exposure at the junction of the Clearwater and Athabasca rivers, "showing limestone and then about ten feet of yellowish clay, followed by at least 100 feet of black shale, which looked like sandstone."

The account which Macoun gives of his journey brings forcibly to attention the vast changes which have taken place in transportation facilities in Western Canada during the past fifty years. Macoun left Fort St. John on the Peace river expecting to meet the Hudson's Bay Company boats ascending the river and to return with them. However, he did not meet these boats and continued down the Peace river to Slave river and then upstream to Athabaska lake and Fort Chipewyan. To reach civilization, he was obliged to cross Lake Athabaska and track his canoes up the Athabaska river to its junction with the Clearwater river, ascend the latter to Methy Portage, cross this portage and follow the canoe and overland route across country to Fort Carleton (now Carleton) on the North Saskatchewan river, descend this river to Lake Winnipeg and proceed through Lake Winnipeg and the Red river to Fort Garry, now Winnipeg. Today, a traveller at Fort Chipewyan could engage a stateroom on a steamer, travel in comfort up the historic Athabaska to Waterways, where he would transfer to a standard sleeper on the Alberta and Great Waterways Railway and proceed by rail to Edmonton, and connect with the transcontinental railways.

Robert Bell[5] descended the Athabaska river in 1882, "to examine more carefully than had hitherto been done, the relations of the rocks of the river, especially with reference to the mode of occurrence of petroleum and asphalt." Bell's discussion of the bituminous sands and his conclusion of their great economic significance are of particular interest. Former observers, particularly Sir John Richardson, found them interesting merely as natural curiosities. Petroleum then was of no value, and the science of geology was in its infancy. Bell regarded the occurrence of the bituminous sands as indication of the existence of a large pool of petroleum in the underlying formations which might be tapped by boring. The bituminous sand he considered to have potential value as a fuel, and for use in making pavements, roofing, drain tile and electrical insulation. He suggested separation of the bitumen from the sand by extraction with oil derived from the lighter constituents of the bitumen and also by means of hot water treatment. It had been reported to him that the bitumen would yield a very superior lubricating oil. He recognized that lack of transportation facilities was a serious handicap to development of oil possibilities in the Athabaska country, but railway lines were already being planned. Possible access to foreign markets was suggested by water transportation to the east end of Athabaska lake and thence by pipe line to Churchill Harbor on Hudson's Bay.

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[5]Report on Part of the Basin of the Athabaska River, North-West Territories. Geological Survey of Canada, 1882-84, part CC.

R. G. McConnell[6] in 1888 made an examination of the hitherto unexplored area lying between the Peace and the Athabaska rivers and north of Lesser Slave lake. In the bituminous sand area, he studied the geology along the Athabaska, McKay, Ells and Muskeg rivers. McConnell believed that the bitumen present in the bituminous sands was the residue of a petroleum which entered the formation from below. He further believed that the rocks from which the petroleum came were exhausted, as the flow had ceased. However, he considered that areas might exist where the original petroleum had been preserved unchanged by evaporation losses and oxidation in the extension of the bituminous sand formation under cover. He advocated that such possibilities be tested by drilling. He estimated that the bituminous sand formation was covered by 700 feet of superimposed strata at Pelican Rapids and by from 1,200 to 1,500 feet of strata at Athabaska Landing.

McLearn[7] in 1917 correlated, on paleontological evidence, the bituminous sands with other members of the Cretaceous series. In the main, the work of McConnell and McLearn forms the basis of our present geological knowledge of the area.

Another member of the Department of Mines, S. C. Ells[8], of the Mines Branch, took up the study of the bituminous sands when the undertaking of the construction of the Alberta and Great Waterways Railway from Edmonton to McMurray revived hopes of industrial activity along the Athabaska river. Ells made his preliminary examination of the bituminous sands in 1913, and his studies are still proceeding. One of his important contributions has been a complete set of topographical maps of the bituminous sand area on which the bituminous sand occurrences are shown. Many other references to his work follow later.

The work of the Scientific and Industrial Research Council of Alberta on the bituminous sands[9] commenced in 1920, coincident with the opening of traffic over the Alberta and Great Waterways Railway to the Clearwater river.

Drilling for Oil.

The Geological Survey of Canada[10], acting on the recommendation of McConnell, started in 1894 the drilling of a well at Athabaska Landing to test the oil producing capacity of the bituminous sand, and underlying formations. Machinery for the work was shipped from Toronto, Ontario, by the Canadian Pacific Railway, which had just recently completed its line to Edmonton. From Edmonton the equipment was hauled by teams one hundred miles northward to Athabaska Landing. Drilling was commenced and at the close of operations for the season, 1,011 feet of hole had been

6R. G. McConnell, Report on a Portion of the District of Athabaska, comprising the country between Peace River and Athabaska River, North of Lesser Slave Lake. Geological Survey of Canada, Vol. V, 1890-91, Sec. D.

7McLearn—Geol. Surv. Can., Sum. Rept., 1918, part C, p. 2. Also Second Annual Report on The Mineral Resources of Alberta, J. A. Allan, p. 15. Report No. 2, Scientific and Industrial Research Council of Alberta.

8Mines Branch Summary Reports, 1913 to date. Preliminary Report on the Bituminous Sands of Northern Alberta, S. C. Ells. Mines Branch Report No. 281, 1914. Bituminous Sands of Northern Alberta, S. C. Ells, Mines Branch Report No. 632, 1926.

9Annual Reports of the Scientific & Industrial Research Council of Alberta.

10 Summary Reports on the Operations of the Geological Survey. Geological Survey of Canada, Vol. VII, p. 6A, 1894; Vol. VIII, p. 8A, 1895; Vol. IX, p. 13A, 1896.

PLATE III.—View of the Athabaska River in the Northern Section of the Bituminous Sand Area.

drilled and cased. The drilling was continued during 1895 and 1896, and the hole carried to a depth of 1,770 feet. Much difficulty was experienced because of the incoherrent nature of the strata encountered. The depth of the strata overlying the bituminous sand horizon proved to be much greater than expected. The hole became so reduced in size that further progress became impossible and the project had be abandoned without reaching the horizon at which oil was expected.

A second boring[11] was undertaken in 1897, near the junction of Pelican and Athabaska rivers, 115 miles below Athabaska Landing. The equipment for this work was transported down stream on rafts and scows. Although many difficulties were encountered the bituminous sand formation was reached, as predicted by McConnell, at a depth of about 740 feet. The formation gave off a strong flow of gas and was found to contain a heavy oil or maltha similar to that associated with the bituminous sand exposures further down the Athabaska river. Drilling was continued to a depth of 820 feet when a tremendous flow of gas was struck. The driller reported that the roar of gas could be heard three miles or more away, and that iron pyrites nodules the size of a walnut were ejected from the bore hole at the speed of a rifle bullet. These conditions made work both difficult and dangerous, so operations were discontinued in the hope that by the following season the flow of gas would have subsided.

When drilling was resumed in 1898, it was soon found that the decreased flow of gas was due merely to the clogging of the bottom of the hole by heavy oil and sand. When this obstruction was cleared away, the pressure was still tremendous, and the gas blew the asphalt up the casing and everything became clogged. Nevertheless the hole was carried to the depth of 837 feet in the face of great difficulty, when a second flow of gas, almost as strong as the first was struck. It had been hoped to carry the bore through the bituminous sand formation into the Devonian limestone below, but the casing had been reduced to 3⅝ inches by this time, and nothing further could be done. The project obviously could not be accomplished without starting again with a much larger hole, and it was abandoned.

Search for the oil pool from which the bitumen of the sands was supposed to be derived was revived by A. Hammerstein, who went into the north country about 1906.[12] Hammerstein drilled a number of wells into the Devonian limestone at points along the Athabaska river from McMurray to McKay Settlement. These wells struck small pockets of gas and showings of bitumen, but nothing of economic importance in the way of oil or gas was found.

Many more borings[13] were made in the bituminous sand area during the period 1910 to 1922, and many petroleum and gas leases

[11]Experimental Boring in Northern Alberta. Geological Survey of Canada, Summary Report, Vol. X, p. 18A, 1897; Vol. XI, p. 28A, 1898.

[12]cf. "The Unexplored West," Railway Lands Branch, Dept. of the Interior, Ottawa, pp. 184-194 for references to Hammerstein and others respecting the bituminous sands.

[13]Ells gives a summary of his own and recorded information about 41 wells drilled in, or adjacent to, the bituminous sand area in his report, "Bituminous Sands of Northern Alberta," Mines Branch, No. 632, 1926, pp. 21-29.

were filed upon. Some of these holes were drilled into the bituminous sands; others penetrated the limestone below. Again nothing of importance was discovered from the standpoint of oil development.

A number of bituminous sand leases and claims were also taken out during this period. In 1920 the Dominion Government withdrew[14] all lands not already leased which contained workable deposits of bituminous sands, and imposed special regulations governing the granting of further leases. The new regulations required that an applicant must have a feasible process for working the bituminous sands to qualify for a lease.

One result of these drilling activities was that beds of rock salt were found in the limestone at the mouth of Horse river and flows of saline water were met in other bore holes. The Government of Alberta, acting on the recommendation of Dr. J. A. Allan, drilled two wells in 1921-2-3 to give definite test of the occurrence of beds of salt,[15] as no reliable records of the former holes had been kept. The first of the test holes was drilled on Lot 8, McMurray Settlement, and a fourteen foot bed of transparent, colorless rock salt was encountered at a depth of 648 feet. Minor beds of salt, associated with anhydrite were found throughout a thickness of forty-three feet. The second test hole in Legal subdivision 5, Section 32, Township 88, Range 8, at Draper, about six miles up the Clearwater valley from the site of the first well, was drilled to a depth of 790 feet to the contact between the Devonian limestone and Precambrian rock. No workable beds of salt were found, but a strong flow of brine was struck at about 670 feet depth. The Alberta Salt Company of Edmonton was organized in 1924 and erected a plant at the mouth of Horse river. Salt brine is pumped from bore holes and evaporated to produce salt.

Use of Bituminous Sand for Pavement Construction.

The idea that the bituminous sands could be used for pavement construction was entertained from an early date. About 1912, enough bituminous sand was brought to Edmonton to lay three sections of sidewalk surface, each of about sixteen square feet, in the business part of the city. These sidewalk sections are still in place.

Tests on a larger scale were carried out by S. C. Ells, of the Mines Branch, Ottawa, in 1915.[16] About sixty tons of bituminous sand, mined in 1914, were hauled by sleighs during the winter 250 miles to Athabaska and from there brought by rail to Edmonton The bituminous sand was worked into pavement aggregate and laid on a concrete foundation prepared by the City of Edmonton along a stretch of 618 yards on the Fort Trail, commencing at 82nd Street and 118th Avenue. The stretch was divided into three approximately equal lengths of sheet asphalt, asphaltic concrete

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14Order-in-Council No. 1495, Ottawa.

15Second Annual Report on The Mineral Resources of Alberta, 1922. J. A. Allan, pp. 102-114; Fourth Annual Report, Scientific and Industrial Research Council of Alberta, 1924, pp. 48-53.

16Bituminous Sands of Northern Alberta, by S. C. Ells, Mines Branch, Ottawa, No. 632, 1926, pp. 75-81.

and bithulithic pavements. The pavement has borne fairly heavy traffic since it was laid, and is still in good condition.

The extension of the Alberta and Great Waterways Railway to the Clearwater river in 1921-22 provided adequate transportation facilities. The question then arose whether bituminous sand could be placed on a competitive basis with other bituminous material. The McMurray Asphaltum and Oil Company, with Thomas Draper as president, acquired a lease close beside the railway, near the old town of Waterways (now called Draper), mined and shipped bituminous sands on a commercial basis, and promoted the use of the material for pavement construction. Mr. Draper has been indefatigable in his efforts to extend the use of bituminous sands. He has done much demonstrational work himself, notably at the Edmonton Exhibition Grounds, and has been instrumental in having other work undertaken. The City of Edmonton, during 1922, secured two carloads of bituminous sand from Mr. Draper, and made it into pavement aggregates for sidewalk surfacing.[17] The following year, the Province of Alberta bought 185 tons of bituminous sand, heated and mixed it with gravel and laid it on 750 feet of roadway on the St. Albert trail[18] at the outskirts of Edmonton. About the same time the Canadian National Railway surfaced its station platform at Tofield, Alberta, with bituminous sands. This later work showed, as former work had done, that the bituminous sand was a suitable material from which to construct pavements. But in addition, it indicated that mining costs and freight rates would have to be reduced in order to place the bituminous sands on a competitive basis with imported asphalt.

Separation of Bitumen from the Bituminous Sands.

The first investigators who considered the economic significance of the bituminous sands recognized that transportation costs would be a serious factor in the utilization of the material in its crude form, where the bitumen is associated with from six to seven times its weight of sand. Separation of the bitumen, at or near the deposits, was suggested. Bell mentioned two methods of separation: extraction with an organic solvent, possibly derived from the oil content of the bituminous sand; and washing with hot water. Hoffman[19] had found by experiment that a bitumen containing half its weight of sand could be prepared by washing with hot water.

Considerable attention has since been given to the question of separating the bitumen content from the Alberta bituminous sands, and much information can be gained from work done on bituminous sands occurring in other parts of the world. S. C. Ells[20] has made experiments on the separation problem and also compiled a summary of a large number of processes that have been tried or proposed for separating the bitumen from Alberta and other bitu-

[17] Third Annual Report of the Scientific and Industrial Research Council of Alberta, 1923, pp. 48-54.

[18] Annual Report of the Department of Public Works of the Province of Alberta, 1923, pp. 19-23.

[19] Chemical Contributions. G. Christian Hoffmann, Geological Survey of Canada, 1880-82, pp. 3-5 H.

[20] "Bituminous Sands of Northern Alberta," S. C. Ells, Mines Branch, No. 632, 1926, pp. 86-113 and pp. 122-235.

minous sands. D. Diver, of Calgary, Alberta, in 1920, made an attempt to distil oil from the bituminous sand beds in situ, near the town of McMurray. A bore hole was drilled into the bituminous sands and a heater installed at the bottom of it. The following year C. E. Dutcher, of San Diego, California, erected a small distillation retort on Hangingstone river. These experiments are of interest as being the first attempts on the ground to distil oil from the bituminous sands, even though no practical results were secured. Jas. D. Tait, of Vancouver, bored a number of wells into the bituminous sands by the use of a jet of hot water in conjunction with drilling tools. He noticed a separation of bitumen from the sand as a result of his hot water jet, and has taken out a patent based on his observations. A. F. Kelsey, a well-known pioneer in bituminous sand work, has also taken out a patent for a separation by aqueous or other solutions. Thos. Draper, of the McMurray Asphaltum and Oil Company, has built retorts at Draper in which he can either destructively distill bituminous sand or subject it to the action of hot water. Mr. Georgeson, of Calgary, has a patent on a process of recovering the bitumen from the bituminous sand beds in situ by the use of steam or hot water under pressure. The idea bears a resemblance to the process developed by Frasch for winning sulphur from the deposits in Texas. The scheme was given a trial in bituminous sand beds underlying the valley of Horse river during the winter of 1924. General W. B. Lindsay, about 1920, promoted an attempt to apply the process of Mark Benson for instantaneous distillation of petroleum with steam under pressure to the distillation of bitumen from the bituminous sands. A large amount of money was spent on development work, and General Lindsay was granted a number of bituminous sand leases. Roland B. Day, during 1924, proposed to treat the material in a type of rotary retort. About the same time Emory B. Smith, of San Francisco, proposed a scheme for manufacture of asphalt pavement blocks. Although no commercial activity has resulted from any of these efforts, they nevertheless form an interesting chapter in the story of the bituminous sands and are worthy of record.

The Road Materials Division of the Scientific and Industrial Research Council of Alberta has persistently studied the problem of separation of the bitumen from the bituminous sands.[21] It has investigated the general method of hot water separation, and has designed and operated a semi-commercial plant with satisfactory results. Approximately 500 tons of bituminous sand were treated in this plant in 1925. Studies of the fundamentals of the process are being continued.

Present Activities.

Each year brings its quota of rumors of important development. Yet each year closes with the situation much the same. However, basic information is being steadily gained and a substantial bituminous sand industry may soon follow. The growing need for suitable road building material in Western Canada appears, at the

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[21]Fourth & Sixth Annual Reports of the Scientific and Industrial Research Council of Alberta.

moment, to be creating the most promising basis for development work. The Federal Department of Mines is turning its attention to the use of bituminous sands for the making of pavements, and in co-operation with the Parks Branch is doing demonstrational construction at Jasper Park. Similar construction will likely be done in co-operation with municipal and other organizations in the West. The Scientific and Industrial Research Council of Alberta will assist in this co-operative work, with its laboratory facilities. It will also continue its own special studies of the separation of the bitumen from the bituminous sands and the application of the separated bitumen to rural road construction.

CHAPTER II.

SCOPE AND METHODS OF INVESTIGATION

Purpose of Investigation.

The field work of the Scientific and Industrial Research Council in the Alberta bituminous sand area was planned to secure detailed information regarding the range of variability of the bituminous sands. In a natural deposit extending over an area of a thousand square miles and having a thickness of as much as two hundred feet in some sections, it is to be expected that the material of which it is composed will show marked variations in nature. Variations are to be looked for from bed to bed vertically through the thickness of the deposit, and also laterally throughout the area covered by the deposit. Such variations have both theoretical and practical significance. Deductions regarding the origin of the deposit will be based largely on the manner in which the materials of which it is composed are found to occur; and commercial development will be controlled to a large extent by the availability of commercial grades of material in the various types of bituminous sand exposures. Since the information so far published about the variability of the bituminous sands was of a very general nature[22], there was need for detailed study.

Method of Field Examination of Exposures.

The plan followed in the field work involved making cross-sections through representative bituminous sand exposures. The appearances and thicknesses of the various beds were recorded and samples of them were collected for laboratory examination. Exposures revealing as great a thickness of beds as possible, and giving opportunity to observe lateral variations, were chosen for study. All parts of the bituminous sand area that can be regarded as reasonably accessible for commercial development were represented by the exposures examined.

Exposures chosen were first trenched from top to bottom and to whatever depth was necessary to get through the surface weathering. The trench was a continuous one, if conditions permitted. Otherwise, it was made in offset sections covering the thickness of the exposed beds. Where rich beds of bituminous sand were crossed, it was only necessary to dig the trench to a depth of a few inches to reach fresh material; but in the case of lean, weathered beds,

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[22]Practically all published information about the bituminous sand deposit has been contributed by the Dept. of Mines, Ottawa. R. G. McConnell (Geol. Surv. Can., Vol. V, 1890-91, Sec. D.) reported on the geology of the area in which the bituminous sands occur. McLearn (Geol. Surv. Can., Sum. Rept., 1913, Part C.) offered a correlation of the Athabaska and Peace river sections which includes the bituminous sand formation.

Since 1913 progress reports by S. C. Ells have appeared yearly in the Summary Reports of the Mines Branch, Dept. of Mines, Ottawa, on his work. This work deals in general with the whole problem of commercial development, but in particular with the preparation of detailed topographical maps of the bituminous sand area. In 1926 he published "Bituminous Sands of Northern Alberta," S. C. Ells, Mines Branch, Dept. of Mines, Ottawa (No. 632, 1926), which covers his work and studies to date. Pages 46 to 59 deal, in a general way, with variations in the deposits.

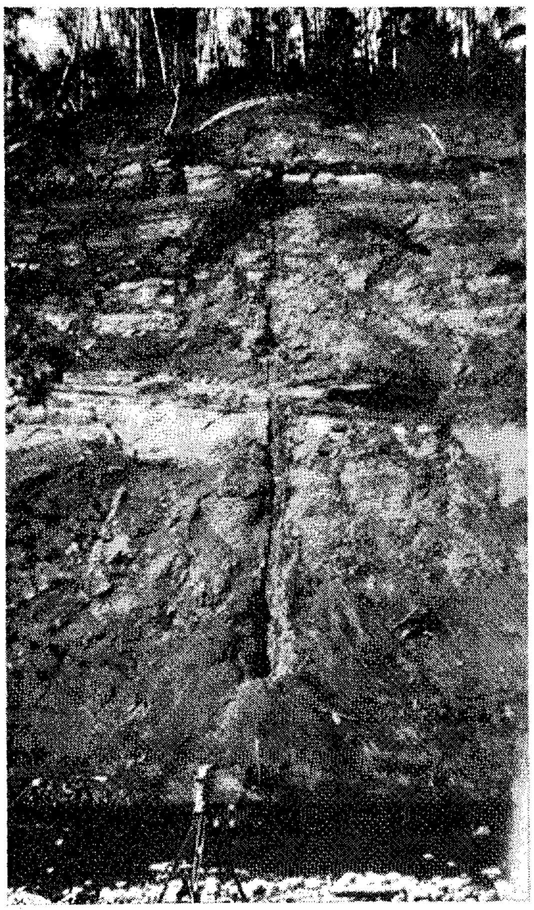

PLATE IV.—Bituminous Sand Exposure with a Trench Dug into Its Face for Examination and Sampling of Strata.

and where talus had accumulated, several feet of material had to be removed. When the entire thickness of fresh beds was brought to light, the beds were examined, divided into logical divisions, and a detailed description of them recorded. A profile of the exposure was prepared, and the position of the points of division of strata accurately located. The exposure was then sampled. A channel sample through each division was cut from the fresh material, exposed by the trench, after all loose material had been removed from the trench and for a reasonable distance along each side of it. A uniform depth of material was cut from the bottom of the trench and caught in a bag. A large sample[23] was thus secured from each division, which was then quartered down to one weighing approximately four pounds for packing and sealing in air-tight quart sample tins for shipment to the laboratory in Edmonton.

Thirty-five exposures were studied. These were distributed along the Athabaska river from McMurray down stream for sixty miles, on Clearwater river, and along tributary streams of these rivers for a number of miles from their mouths, thus: Christina river, 8 miles; Hangingstone river, 4 miles; Horse river, 4 miles; Steepbank river, 8 miles; Muskeg river, 4 miles; McKay river, 10 miles; and Ells river, 10 miles. The location of these exposures is shown in the accompanying map No. 2. Approximately two hundred and twenty-five bituminous sand samples were collected for laboratory examination.

Sinking of a Shaft.

In addition to the examination of exposures, a shaft was sunk through approximately thirty feet of rich bituminous sand beds. This project was undertaken to obtain information on a number of points. In the first place it was desired to examine bituminous sand lying well back from surfaces exposed to the weather. All the studies of exposures were of necessity dealing with bituminous sand lying close to the weathering zone. Examination of material excavated from such a shaft would give data to indicate the degree to which samples taken from exposure trenches had been influenced by surface weathering. In the second place it was of interest to observe whether the bitumen in fresh, rich bituminous sands would move into an excavation dug into them. The success attending the winning of petroleum in Alsace by shafts and galleries in an oil sand formation had turned attention to the possibility of success in applying similar methods to the Alberta bituminous sand formation.[24] And, finally, it was thought that the experience of digging a shaft through bituminous sand beds would bring out some

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[23]The large sample weighed from fifty to one hundred pounds. This weight varied with the thickness of the strata sampled.

[24]Exploitation du Petrole par Puits et Galeries, Paul de Chambrier, Dunod, Paris, 1921.

Working Petroleum by Means of Shafts and Galleries, Paul de Chambrier, J. Inst. Petr. Tech., July, 1921. See also contribution to the discussion of this paper by Cunningham Craig, p. 191.

An Economic Study of the Winning of Petroleum by the Method of Underground Drainage, Paul de Chambrier. A communication to the International Congress on Liquid Fuels, organized by the Society of Industrial Chemistry at Paris, October, 1922.

Recovery of Petroleum by Shafts and Galleries at Pechelbronn, Alsace, France, and at Wietze, Hanover, Germany, by Charles Camsell and Arthur Buisson, Memorandum Series No. 10, Mines Branch, Dept. of Mines, Ottawa, Canada, 1924.

useful information about the practical problem of excavating this type of material.

The site for the shaft was in the valley of Horse river on a flat where rich beds of bituminous sand occurred overlain by about fifteen feet of overburden. This site was about one mile and a half upstream from the mouth, and about one hundred feet back from the river's edge.[25] The shaft was four feet square and was sunk to a depth of forty-five feet. This depth placed the bottom of the shaft twenty feet below the water level in the river. The excavating was done by pick and shovel, with the assistance of slow explosives. The shaft through the overburden was cribbed tightly with lumber. The part through the bituminous sands was cribbed with flattened poles set vertically, but a section of one side was left unobstructed to make possible subsequent observation. The material penetrated by the shaft was examined and sampled.

Laboratory Examination of Samples.

All bituminous sand samples collected during the course of the field work were placed in push-top tins at the time of sampling, and from time to time were crated and sent to the laboratory at Edmonton for examination. This examination was proceeded with at once, and most of the determinations were completed within three months of the time of sampling.[26] The samples were analysed for bitumen, water and mineral matter; the bitumen was examined for specific gravity and sulphur; and the mechanical grading of the mineral matter was determined. This work was done as follows. The water plus bitumen content was found by extracting the bituminous sand with benzene,[27] and drying and weighing the extracted sand. The water content was determined separately by the Distillation Method of the American Society for Testing Materials.[28] A sample of the bitumen was secured for specific gravity and sulphur determinations by carefully distilling off the bulk of the benzene from the extraction of the bituminous sand sample, and evaporating the remaining solvent on a water-bath. Specific gravity determinations were made by means of picnometers. Sulphur determinations were made by the bomb method. Tyler standard sieves were used for the mechanical analyses of the extracted mineral matter.

It was decided that it was inexpedient and unnecessary to make all laboratory determinations on the samples in duplicate. The plan was adopted of including one duplicate in each batch of samples put through the routine to keep the technique of the work checked up, and to give data that would reveal the degree of accuracy of the results.

25The shaft was situated on the bituminous sand reserve of the Parks Branch, Department of Interior, Ottawa, Canada. Thanks are due to the Parks Commissioner for permission to sink the shaft.

26Most of the determinations of the sulphur content of the extracted bitumen were made at a later period. A number of specific gravity determinations were checked a year and a half later. Except where gross errors were discovered, no differences were observed from the values obtained on first examination. The samples had been stored in the push-top tins.

27Benzene rather than carbon disulphide was used, because the extracted bitumen was to be analysed for sulphur content.

28A. S. T. M. Standard Test D-95-24.

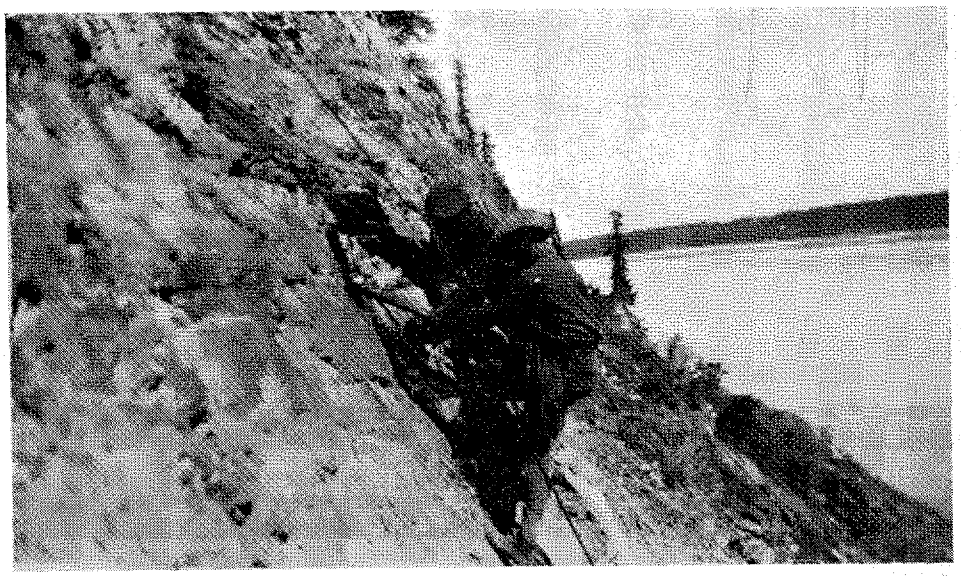

PLATE V.—Collecting Samples from a Trench on a Bituminous Sand Exposure.

Accuracy of Determinations.

Determinations of the percentage of bitumen, mineral matter, and water contained in the samples were checked in fifty-three cases. The average deviations between pairs of check percentages were: for bitumen, 0.2; for mineral matter, 0.3; and for water, 0.1.

Determinations of the mechanical analyses of mineral matter were checked in forty-two cases. The average deviation between pairs of check figures for the percentages retained on the 48, 100 and 200 mesh sieves, and passing the 200 mesh sieve were, respectitvely, 1-2-2-1.

Specific gravity determinations were checked in fifty-six cases. The average deviation between pairs of check values was 0.004. Specific gravity values have been recorded to the nearest five in the third decimal. Difficulty was experienced in getting satisfactory determinations in the few cases where the specific gravities were greater than 1.04. Such bitumen is very hard and causes trouble while the solvent is being evaporated off, and bubbles form in the bitumen when poured into the picnometer. However, such high values can have no further interpretation than that the bitumen has been badly weathered.

Sulphur determinations have been reported to the nearest per cent. These were made simply to detect any marked variation in sulphur content of bitumens from different sections of the bituminous area. An accuracy greater than what was required for this purpose was not attempted.

CHAPTER III.
PRESENTATION OF DATA

FIELD EXAMINATION OF CROSS-SECTIONS

DESCRIPTION OF STRATA No. 1.
CROSS-SECTION No. 1—HORSE RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Friable sandstone or compacted sand bands. Sandstone 18 feet thick appears a short distance to west of the cross-section. Color of sandstone changes from white to brown as underlying bituminous sand is approached. Obvious stratification and some cross bedding appear in upper part of division. Lower part lies conformably on bituminous sand bands below	25.4
2 A	Decidedly brown, compact sand	3.0
2 B	Hard, black bituminous sand, approaching a bituminous sandstone	5.0
2 C	Bituminous sand; fractured surface, black in top beds, brown in lower ones; all beds weather to a grey color..	9.9
2 D	Hard, bituminous sandstone causing cliff formation along the exposure	2.5
3	Eight feet of shale containing a few bands of rich bituminous sand underlain by hard, massive bituminous sand with a few very thin bands of shale. Some salt crystals appear on surface of shale bands	20.7
4	Hard, massive bituminous sand with some very thin bands of shale	13.9
5	Hard, massive bituminous sand with some thin bands of shale underlain by 10 feet of alternating bituminous sand and shale each about 15 inches thick	23.2
6	Hard, lean bituminous sand. A 3-foot band of shale occurs 9 feet below the top of this division	25.8
7 A & B	Massive bands of soft, rich bituminous sand, containing very few lean divisions. Upper and lower halves were sampled separately	42.3
	Total thickness of strata examined	171.7

LABORATORY EXAMINATION OF SAMPLES FROM CROSS-SECTIONS

TABLE No. 1

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 1—HORSE RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	....	....	....	....	71	28	1	....	..
2*	9.6	87.7	2.7	....	31	53	16	1.030	5
2A	8.6	90.8	0.6	3	75	19	3	1.060	5
2B	7.9	91.2	0.9	....	8	78	14	1.060	5
3	10.0	89.4	0.6	2	40	40	18	1.020	5
4	12.4	86.2	1.4	1	47	42	10	1.025	5
5	8.2	88.6	3.2	....	38	41	21	1.030	5
6	7.4	91.1	1.5	....	41	43	16	1.030	5
7A	15.1	83.8	1.1	....	39	53	8	1.025	5
7B	15.1	84.4	0.5	....	51	43	6	1.025	..
†	14.6	84.3	1.1	1	45	48	6	1.025	5

*Sample 2, aggregate sample 2A to 2D.
†Sample from an exposure upstream from the cross-section.

DESCRIPTION OF STRATA No. 2

CROSS-SECTION No. 2—HORSE RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1 A	Very lean bituminous sand with bands of shale interbedded; obviously weathered	3.3
1 B	Lean but massive bituminous sand; shale bands fewer and thinner than in 1A; prominent shale band 30 inches thick near centre of 1B with showing of white salt crystals*	10.0
2	Uniform, hard, massive, cliff-forming bituminous sand of medium richness	12.3
3 A	Massive, fairly rich, cliff-forming bituminous sand......	6.1
3 B	Massive, hard, cliff-forming bituminous sand; leaner and more stratified than 3A	10.2
4	Massive bituminous sand, showing irregular fracture; lean at top, getting richer toward the bottom; salt crystallizes out along lines of minor stratification, especially at the bottom of this division	7.7
5,A,B,C,D	Massive, rich bituminous sand; crossbedding apparent; fracture parallel to the face; bitumen seeping out has coated the face of B in some places. A was 6.5 ft., B 9.7 ft., C 19.9 ft., and D 11.9 ft................................	48.0
	Total thickness of strata examined........	97.6

*The sale crystals found on the surface of bituminous sand exposures are not necessarily crystals of common salt (sodium chloride). An analysis of a sample of this showing gave: Ferrous sulphate 13%; Calcium sulphate, 36%; magnesium sulphate, 32%, and Sodium sulphate, 19%.

TABLE No. 2

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 2—HORSE RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1A	1.6	92.6	5.8	....	9	43	48	....	..
1B	4.5	92.2	3.3	....	3	67	30	1.025	5
1B, Shaley part	5.2	90.2	4.6	....	7	57	36	1.025	5
2	9.2	86.7	4.1	....	3	77	20	1.030	..
3A	14.5	84.2	1.3	....	6	76	18	1.025	5
3B	10.6	89.2	0.2	....	31	56	13	1.030	..
4	8.5	91.2	0.3	....	18	69	13	1.025	..
5A	11.5	88.0	0.5	....	45	48	7	1.025	5
5B	14.2	85.2	0.6	1	33	53	13	1.025	..
5C	15.5	83.7	0.8	1	57	35	7	1.025	..
5D	17.4	82.2	0.4	....	27	65	8	1.025	5

DESCRIPTION OF STRATA No. 3

CROSS SECTION No. 3—HANGINGSTONE RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1 A	Clean, white sand	2.1
1 B	Sand of mottled appearance	3.1
2	Alternating bands of hard bituminous sand and shale of about 6 inches thickness. Bottom 3 feet consists entirely of very hard bituminous sand	9.0
3	Bituminous shale	2.7
4	Thick bands of bituminous sand, very hard at top and causing cliffs along the outcrop, but getting softer and richer in bitumen toward the bottom	26.3
5 A	Shale bands 6 feet thick underlain by 20 inches of lean, hard bituminous sand, followed by alternating bands of bituminous sand and shale, the former 12 to 30 inches thick and fairly rich, the latter 6 to 10 inches thick. Three shale bands 20 inches thick occur near the top, middle and bottom of division	13.3
5 B	Bituminous sand free from shale. This lens appears much thicker along the outcrop to the east of the cross-section	4.8
6 A, B	Lean bands of bituminous sand interbedded with clayey shale. Division into A & B was for purpose of sampling. 6A appears to have more of the clayey shale than 6B. Whole division consists of material that could be dug with ease. Weathers readily forming a slope up to cliff above. A was 14.9 ft., and B 16.2 ft.	31.1
7	Soft, wet clay revealed by deepening the trench	10.8
8 A	Sand almost devoid of bitumen	6.0
8 B	Hard, lean bituminous sand	5.2
8 C	Cliff-forming strata of bituminous sand immediately above the water level along the outcrop. Close stratification and cross bedding shown	5.1
	Total thickness of strata examined	119.5

DESCRIPTION OF STRATA No. 4

CROSS-SECTION No. 4A—HANGINGSTONE RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Hard, stratified sand carrying some bitumen, particularly in the lower part	11.2
2	Lean bituminous sand, stratification very obvious	16.3
3 A, B	Massive bands of bituminous sand of uniform nature except for two small bands, 40 and 24 inches thick of material much harder than the rest. A was 11.0 ft., and B 11.0 ft.	22.0
4	Upper half consists of thin bands of very lean bituminous sand; lower half consists of a lens of alternating 4-inch layers of rich bituminous sand and 1-inch layers of lean material. The trench crosses this lens at its greatest thickness	8.7
5 A	Massive, rich, fairly soft bituminous sand. This band pinches out to the north	7.5
5 B	Grey, clayey material	7.2
5 C	Lean, bituminous sand of a very fine texture	4.3
5 D	Lean bituminous sand	4.3
	Total thickness of strata examined	81.5

TABLE No. 3

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 3—HANGINGSTONE RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1A	0.0	96.0	4.0	....	18	76	6	....	..
1B	1.7	93.4	4.9	....	12	61	27	Very hard	..
2	7.4	88.1	4.5	....	22	49	29	1.030	..
3	3.7	87.8	8.5	....	28	51	21	1.025	..
4	13.0	85.9	1.1	....	27	64	9	1.030	5
5A	6.9	86.3	6.8	7	40	34	19	1.030	..
5B	10.7	87.3	2.0	*37	40	16	7	1.030	5
6A	4.1	87.1	8.8	1	20	40	39	1.025	..
6B	4.6	87.6	7.8	1	23	46	30	1.035	..
7	0.5	84.9	14.6	....	20	29	51	....	..
8A	2.1	95.9	2.0	16	76	6	2	1.025	5
8B	8.5	89.6	1.9	18	73	6	3	1.030	..
8C	12.6	86.6	0.8	23	63	9	5	1.025	5

*Coarse white quartz sand.

TABLE No. 4

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 4A—HANGINGSTONE RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1	2.0	92.9	5.1	....	8	44	48	....	..
2	8.5	89.3	2.2	1	22	57	20	....	..
3A	10.8	86.2	3.0	....	19	68	13	1.035	5
3B	12.4	84.5	3.1	1	56	33	10	1.020	..
4	6.1	84.3	9.6	2	14	50	34	1.015	..
5A	12.8	84.7	2.5	....	69	27	4	1.020	4
5B	1.6	85.9	12.5	....	13	30	57	....	..
5C	4.1	88.0	7.9	....	10	54	36	1.015	..
5D	8.6	85.8	5.6	1	20	62	17	1.015	5

DESCRIPTION OF STRATA No. 5

CROSS SECTIONS 4B, C, D, E, F, G—HANGINGSTONE RIVER

Cross-Section.	Division of Strata.	DESCRIPTION.	Thickness in Feet.
4B	1	Clayey shale and thin layers of bituminous sand..	22.2
	2	Rich, fairly soft, bituminous sand........................	6.3
		Total thickness of strata examined........	28.5
4C		Fairly rich, soft bituminous sand............................	20.6
		Total thickness of strata examined........	20.6
4D	1	Lean, stratified bituminous sand, including a few bands of shale	4.9
	2	Fairly rich bituminous sand	11.6
		Total thickness of strata examined——	16.5
4E		Fairly hard bituminous sand, upper part finely stratified	22.3
		Total thickness of strata examined........	22.3
4F		Bituminous sand, upper part finely stratified, lower part massive and fairly rich..........................	21.2
		Total thickness of strata examined........	21.2
4G		Finely stratified lean bituminous sand.................	16.1
		Total thickness of strata examined........	16.1

These are a series of small exposures scattered along the Hangingstone river for two miles upstream from cross-section 4A. The river level rises about 100 feet in the two miles. Consequently the exposures along the river represent successively higher beds of the bituminous sand formation extending throughout the thickness of strata exposed in cross-section No. 4A.

TABLE No. 5

ANALYSES OF SAMPLES FROM

CROSS-SECTION Nos. 4B, C, D, E, F, G—HANGINGSTONE RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
Cross-Section 4B									
1	4.2	86.2	9.6	1	43	30	26	1.015	..
2	13.2	81.6	5.2	2	41	52	5	1.015	..
Cross-Section 4C									
1	11.0	86.7	2.3	....	13	78	9	1.030	4
Cross-Section 4D									
1	7.4	91.3	1.3	....	36	59	5	1.025	..
2	12.4	85.1	2.5	....	56	37	7	1.020	..
Cross-Section 4E									
1	8.4	88.3	3.3	....	52	39	9	1.025	5
Cross-Section 4F									
1	9.4	86.7	3.9	2	63	29	6	1.015	4
Cross-Section 4G									
1	5.3	83.6	11.1	....	26	53	21	1.020	..

DESCRIPTION OF STRATA No. 6

CROSS-SECTIONS Nos. 5A & 5B—HORSE RIVER

Cross-Section.	Division of Strata.	DESCRIPTION.	Thickness in Feet.
5A	1A	Massive, rich, bituminous sand...............................	5.0
	1B	Massive, rich bituminous sand, separated from A because of a difference in the stratification........	6.2
		Total thickness of strata examined........	11.2
5B		Massive, rich bituminous sand	4.3
		Total thickness of strata examined........	4.3

These cross-sections are of material covered by very light overburden on river flat. Both cross-sections are adjacent to the shaft, but are at slightly different elevations.

DESCRIPTION OF STRATA No. 7

SHAFT—HORSE RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
Overburden	Bands of sand, sandy clay, bituminous sand rubble and boulders. Boulders occur at bottom of overburden, immediately overlying the bituminous sand..	15.0
Strata	Massive, uniform beds of rich, bituminous sand. One thin parting of hard bituminous sand encountered. A number of marcasite nodules varying in size from one to six inches in diameter were found imbedded in the bituminous sand. Some cross-bedding observed	30.0
	Total thickness of strata examined........	45.0

An auger hole drilled 4 feet into bottom of shaft reached a layer of clay. This clay probably represents the bottom of the bituminous sand formation. Water smelling strongly of hydrogen sulphide entered the shaft from this clay. The only other water that entered the shaft, excepting drops which formed on the walls of the shaft, was that which came in from immediately beneath the overburden.

TABLE No. 6

ANALYSES OF SAMPLES FROM
CROSS-SECTIONS Nos. 5A & 5B—HORSE RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	100	200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
Cross-Section 5A									
1A	17.4	82.1	0.5	....	41	51	8	1.025	..
1B	16.1	81.5	2.4	....	46	44	10	1.025	..
Cross-Section 5B									
1	16.8	82.9	0.3	....	47	48	5	1.025	5

TABLE No. 7

ANALYSES OF SAMPLES FROM
SHAFT ON HORSE RIVER

Depth in Shaft	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	100	200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
15-17 feet ..	13.1	81.6	5.3	....	47	48	5	1.020	5
17-19 " ..	14.4	81.1	4.5	....	50	45	5	1.020	5
19-21 " ..	16.0	80.9	3.1	....	41	52	7	1.020	5
21-23 " ..	14.9	81.7	3.4	....	47	46	7	1.020	5
23-25 " ..	15.9	81.9	2.2	....	57	37	6	1.020	5
25-27 " ..	15.8	80.6	3.6	....	51	42	7	1.020	..
27-29 " ..	16.0	81.9	2.1	....	57	38	5	1.020	5
29-31 " ..	16.7	80.2	3.1	....	64	33	3	1.020	..
31-33 " ..	15.6	81.8	2.6	....	48	47	5	1.020	5
33-35 " ..	17.2	80.5	2.3	....	62	32	6	1.020	..
35-37 " ..	12.2	80.4	7.4	3	59	25	13	1.020	5
37-39 " ..	16.0	79.7	4.3	....	69	26	5	1.020	..
39-41 " ..	15.6	79.5	4.9	....	80	15	5	1.025	5
42.5 " ..	10.8	72.6	16.6	14	..65	16	5	1.025	5

DESCRIPTION OF STRATA No. 8

CROSS-SECTION No. 6—CHRISTINA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Stratification is very evident. This division is roughly divided into two parts by a difference in the bedding, but the bitumen content and the nature of the sand are the same in each	9.4
2	Alternating bands of fairly rich, hard bituminous sand, and bands of shale	5.4
3	Rich, fairly soft bituminous sand, the sand exceptionally coarse	4.0
	Total thickness of strata examined	18.8

Small exposure showing part of the thickness of bituminous sand beds underlying the Oxbow on the Parks Branch bituminous sand reservation on Christina river.

DESCRIPTION OF STRATA No. 9

CROSS-SECTION No. 7—CHRISTINA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Stratified sand, carrying small amount of bitumen, especially toward bottom of division	10.6
2	Band of rich bituminous sand, hard and chunky at top but otherwise soft and uniform in nature	7.9
3	Wet, plastic clayey sand carrying a small amount of bitumen	8.7
4	Lean bituminous sand	3.5
5	Bands of clay and shale containing very little bitumen	28.6
6	Soft, rich bituminous sand	19.1
7	Massive, fairly hard, but rich bituminous sand	10.6
8	Bands of bituminous sand and shale	2.5
9	Bituminous sand, more massive and richer toward the bottom	9.4
10	Sandy shale and dry, lean bituminous sand	3.2
11	An 18-inch band of hard bituminous sand, underlain by rich, massive bituminous sand stratified into bands approximately 30 inches thick	17.1
	Total thickness of strata examined	121.2

This section was made in two parts, the trench through divisions 8 to 11 being offset to the north of that through divisions 1 to 7 in order to avoid the talus.

TABLE No. 8

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 6—CHRISTINA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25° /25° Cent.	Sulphur Content %
				48	100	200	200		
1	12.1	87.7	0.2	18	52	25	5	1.030	5
2	3.0	96.0	1.0	29	47	16	8	....	..
3	9.7	88.4	1.9	78	13	5	4	1.030	..

TABLE No. 9

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 7—CHRISTINA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25° /25° Cent.	Sulphur Content %
				48	100	200	200		
1 South	1.3	89.5	9.2	....	29	35	36	....	..
2 "	12.0	83.8	4.2	....	78	15	7	1.020	4
3 "	2.8	83.8	13.4	....	20	33	47	1.025	..
4 "	9.0	82.1	8.9	....	48	34	18	1.025	..
5 "	2.1	85.6	12.3	....	21	37	42	....	..
6 "	10.2	83.5	6.3	....	44	39	17	1.020	..
7 North	11.9	85.1	3.0	5	31	50	14	1.020	..
8 "	8.2	88.8	3.0	1	34	34	31	1.015	..
9 "	13.6	83.3	3.1	....	62	29	9	1.030	4
10 "	3.4	90.5	6.1	....	42	34	24	1.020	..
11 "	13.2	84.4	2.4	1	50	38	11	1.020	4

DESCRIPTION OF STRATA No. 10

CROSS-SECTION No. 8—CHRISTINA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Bituminous sand prominently stratified into bands 6 to 18 inches thick	5.5
2	Variable and much stratified beds of lean bituminous sand with considerable clayey material	10.7
3	Soft bituminous sand becoming harder and leaner at the top of the division	14.9
4	Lean, loose bituminous sand, showing little stratification except at top of division where a few bands of rich bituminous sand occur	24.0
5	Bands of bituminous sand from 2 to 6 inches thick, separated by bands of light colored clayey shale about 2 inches thick in the middle portion of the division, but thinner toward the bottom and thicker toward the top..	16.8
6	Upper 5 feet hard, massive bituminous sand stratified in approximately 2 foot bands and showing decided fracture parallel to the face of exposure. Next 5 feet bituminous sand with irregular partings of lignite and lignitic wood ½ inch thick lying on layers of fine, white quartz gravel about 6 inches apart. One fairly complete piece of an 8-inch log of lignitic wood was observed. Lower part of division is massive, hard, lean bituminous sand, standing out in prominent cliff formation	19.4
7	Bituminous sand not so massive or cliff-forming in nature as that in 6. Tendency to flake off parallel to face has allowed weathering to take place to a considerable depth back from face and trench did not reach fresh material	24.5
8	Hard bituminous sand of cliff-forming nature and pronounced fracture parallel to face. Considerable talus was removed to reveal part of the thickness of division. The bottom of the bituminous sand formation was not reached. It seems probable from neighboring indications, however, that it is a short distance below the base of this division	25.2
	Total thickness of strata examined	141.0

Limestone outcrops 150 yards down stream at an elevation corresponding to a point a short depth below the bottom of 8.

TABLE No. 10

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 8—CHRISTINA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25° /25° Cent.	Sulphur Content %
				48	100	200	200		
1	8.6	88.8	2.6	6	14	61	19	1.025	..
2	3.5	87.7	8.8	1	17	44	38	....	..
3	8.3	86.3	5.4	2	24	55	19	1.020	6
4	4.0	86.1	9.9	4	18	49	29	1.040	..
5	6.4	87.1	6.5	5	14	60	21	1.035	..
6	9.1	88.4	2.5	3	19	58	20	1.035	..
7	8.4	87.6	4.0	5	41	45	9	1.040	..
8	12.3	84.8	2.9	1	18	72	9	1.035	5

DESCRIPTION OF STRATA No. 11

CROSS-SECTION No. 9—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Bands of very lean bituminous sand separated by others of clayey shale and yellowish to reddish brown sand. These bands were reached by trenching through 30 inches of dirt covered with grass and bushes....................	30.5
2	Bituminous sand of variable nature, some very hard and some richer than the rest	13.4
3	Hard, decidedly stratified bituminous sand	23.0
4	Fairly uniform bituminous sand with approximately 2 inches shaley bands from 12 to 24 inches apart. Material is black and dry	24.4
5	Fairly massive, cliff-forming bituminous sand in beds about 18 inches thick separated by clay partings ½ inch to 1 inch thick. Material seems hardened and weathered	21.3
6	Cliff-forming bituminous sand, very similar to 5. Was separated from 5 for purpose of extra sample.............	18.6
7	Fairly rich, dry bituminous sand	16.8
8	Alternating beds of lean and fairly rich bituminous sand from 4 to 12 inches thick. Lean material is of nature of bituminous sandstone; richer material is black, weathered, dried and non-plastic	23.9
9	Lean, brown colored material of nature of bituminous sandstone. Talus was dug away to uncover this band to a thickness of	16.1
	Total thickness of strata examined........	188.0

The face of this outcrop was badly weathered as is the case with all the bituminous sand exposures along this part of the Athabaska river. It was chosen for examination because of the thickness of strata exposed and because it gave opportunity for comparing the series of exposures on the Athabaska river below McMurray with those examined on Horse and Hangingstone rivers. The weathered material was removed as completely as possible by trenching.

DESCRIPTION OF STRATA No. 12

CROSS-SECTION No. 10—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Variable, lean, brown colored, hard bituminous sand, in beds about 24 inches thick, in which false bedding is apparent	13.7
2	Massive, hard, grey weathered bituminous sand...........	19.4
3	Massive, black, fairly hard bituminous sand. Small showing of salt crystals where water seeps to the face...........	16.8
	Total thickness of strata examined........	49.9

This cross-section was made at a point along a series of bituminous sand outcrops on the east side of the river. The lower strata are concealed by a covering of dirt in which trees have grown up and by seepage material and bituminous sand which has got into a mobile state and has flowed out along the base of the outcrop.

A composite sample was collected from four places in bituminous sand which had flowed out along the shore-line. Water moving through this sort of material causes a certain amount of separation of bitumen which appears on the surface of pools of water.

Limestone outcrops to a height of 12 to 15 feet above the river one-half mile upstream, and to a similar height three-quarters of a mile downstream from this section. The cross-section is apparently on a synclinal fold in the limestone.

TABLE No. 11

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 9—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	1.0	87.8	11.2	....	22	40	38	1.060	..
2	7.5	85.8	6.7	....	41	45	14	1,055	4
3	4.4	89.0	6.6	....	34	46	20	1.065	..
4	8.3	85.9	5.8	....	38	53	9	1.025	..
5	9.1	87.9	3.0	....	47	42	11	1.035	4
6	9.5	89.4	1.1	....	50	39	11	1.025	..
7	13.0	83.2	3.8	....	80	14	6	1.030	4
8	5.3	87.0	7.7	2	67	18	13	1,025	..
9	4.7	87.5	7.8	11	43	30	16	1.070	..

TABLE No. 12

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 10—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	7.7	90.0	2.3	2	34	53	11	1.060	..
2	11.7	86.3	2.0	1	30	56	13	1.060	..
3	12.5	84.0	3.5	....	17	72	11	1.030	4
*4	16.8	81.1	2.1	31	30	28	11	1.020	..

*Sample from shore line.

DESCRIPTION OF STRATA No. 13

CROSS-SECTION No. 11—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Hard, grey, weathered, broken bituminous sand bands....	9.6
2A	Hard, dry, weathered bituminous sand forming a cliff....	6.9
2B	Massive bituminous sand bands	11.4
2C	Massive bituminous sand bands very similar to 2A..........	9.6
3	Variable bands and lenses of bituminous sand, richer at the top, resting on a 14-inch band of clay with leaner bands of bituminous sand below	4.9
4	Massive, rich bituminous sand. Talus was removed till the bands exposed had a thickness of..............................	9.3
	Total thickness of strata examined........	51.7

This cross-section and No. 10 were made on the same series of bituminous sand exposures. No. 11 was made on a hogsback formed by a small stream entering the river and from which the overburden has been eroded away from the bituminous sand. The lower divisions of the exposure are concealed by talus and other accumulated material.

A sample of the bituminous sand that had flowed out along the shore line was collected at this cross-section.

DESCRIPTION OF STRATA No. 14

CROSS-SECTION No. 12—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Fairly rich and soft massive bituminous sand, with a few very small partings of clay..	9.9
2	Fairly rich and soft, massive, cliff-forming bituminous sand	9.8
	Total thickness of strata examined........	19.7

The exposed bands here represent only a part of the formation. The lower bands are concealed by talus while the upper are weathered and eroded back from the exposure to form a gradual slope covered with jack-pine.

TABLE No. 13

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 11—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	9.5	84.3	6.2	1	67	19	13	1.040	..
2A	9.7	89.1	1.2	2	87	8	3	1.055	..
2B	13.2	82.6	4.2	4	60	27	9	1.020	3
2C	12.4	83.0	4.6	3	76	16	5	1.025	..
3	6.1	87.9	6.0	26	47	18	9	1.030	..
4	13.1	82.1	4.8	....	52	40	8	1.025	4
*	17.6	80.5	1.9	....	58	36	6	1.020	..

*Sample from shore line.

TABLE No. 14

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 12—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	13.0	81.8	5.2	....	33	58	9	1.035	..
2	12.4	83.8	3.8	....	13	74	13	1.025	4

DESCRIPTION OF STRATA No. 15

CROSS-SECTION No. 13—STEEPBANK RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Upper bands are lean bituminous sand; thin bands of hard sandstone occur in middle of division; below are more massive but lean bituminous sand	17.8
2	Massive, fairly rich bituminous sand, leaner at the top than below; in bands from 12 to 24 inches thick	17.1
3	Massive, fairly soft and rich bituminous sand with several bands of clay	10.7
4A	Hard, lean bituminous sand underlain by clay	2.9
4B	Rich, fairly soft, massive bituminous sand	20.4
4C	Rich, massive bituminous sand. Some bitumen seepages occur along the top of clay partings in this division	35.3
4D	Rich, soft bituminous sand	28.2
	Total thickness of strata examined	132.4

A sample of bitumen was collected from the seepages on the exposure at this cross-section.

DESCRIPTION OF STRATA No. 16

CROSS-SECTION No. 14A—STEEPBANK RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Hard, lean, massive bands of bituminous sand weathered brown	14.0
1B	Hard, black, dry, massive bituminous sand	5.0
1C	Lens of hard, massive bituminous sand	7.0
—	Covered by accumulation of dirt and growth of trees	35.5
2	Alternating bands of rich, soft and lean bituminous sand	17.1
—	Covered by accumulation of dirt and growth of trees	36.4
3	Alternating bands of about 18-inch thick of rich and lean bituminous sand	9.3
4A	Bands of soft and hard, massive, fairly rich bituminous sand	9.5
4B	Uniform, soft, rich, massive bituminous sand	15.0
4C	Small band of material underlying the rich bituminous sand of 4B. Consists of very fine sand with two layers of fine, white quartz gravel, ½ and 1-inch thick. Gravel is at the bottom and 6 inches from the top of this division	2.3
4D	Thick, massive bands of bituminous sand of variable nature. Some gravel layers occur. Broken limestone is mixed into the bituminous sand at the bottom of this division	11.0
	Total thickness of strata examined	162.1

The formation in this area is covered by a thin overburden, the majority of which, except in the immediate vicinity of the valley, is covered by swamp.

TABLE No. 15

ANALYSES OF SAMPLES FROM

CROSS-SECTION No. 13—STEEPBANK RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	4.5	90.7	4.8	4	16	59	21	1.040	..
2	9.3	86.2	4.5	....	22	62	16	1.025	..
3	10.8	84.3	4.9	....	29	60	11	1.030	4
4A	5.0	91.8	3.2	....	34	62	4	1.025	..
4B	12.8	83.6	3.6	....	56	38	6	1.025	4
4C	13.1	83.7	3.2	....	54	39	7	1.010	..
4D	13.8	82.2	4.0	....	46	46	8	1.015	4
*	29.2	62.6	8.2	1	29	40	24	1.005	4

*Bitumen seepage along outcrop.

TABLE No. 16

ANALYSES OF SAMPLES FROM

CROSS-SECTION No. 14A—STEEPBANK RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1A	4.4	92.7	2.9	1	17	52	30	....	..
1B	6.4	91.6	2.0	7	8	47	38	1.035	..
1C	4.9	86.4	8.7	5	5	34	56	1.040	..
2	8.6	84.6	6.8	1	14	60	25	1.015	5
3	7.2	86.2	6.6	1	16	69	14	1.035	5
4A	11.2	84.6	4.2	....	15	72	13	1.025	..
4B	13.5	82.4	4.1	....	24	68	8	1.015	5
4C	5.9	88.1	6.0	26	23	37	14	1.035	..
4D	3.4	92.4	4.2	42	44	9	5	1.015	..

DESCRIPTION OF STRATA No. 17

CROSS-SECTION No. 14B—STEEPBANK RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Rich, massive, uniform bituminous sand. The bottom 18 inches overlying the coal seam below is somewhat leaner and harder than the rest	17.6
2	Coal seam. Shaley, excessively laminated at top; 3 feet of apparently fairly good lignite below. The limestone immediately underlies the coal	4.0
	Total thickness of strata examined	21.6

DESCRIPTION OF STRATA No. 18

CROSS-SECTION No. 15—McKAY RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Variable bands of hard bituminous sand, soft bituminous sand, and of shale	15.8
2	Hard, fairly brown colored bituminous sand of cliff-forming nature	21.5
3	Similar to 2, but somewhat harder	5.8
4A	Rich, soft bituminous sand	6.7
4B	Harder and leaner bituminous sand than in 4A. At the bottom of this division a seam of coal 7 inches thick occurs overlying a 4-inch bed of clay	11.0
5	Fairly hard, cliff-forming bituminous sand, similar to 2	8.8
6	Wet, shaley, clayey material covered with talus, but exposed by trenching to a depth of	7.7
	Total thickness of strata examined	77.3

TABLE No. 17

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 14B—STEEPBANK RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	11.6	83.6	4.8	1	23	62	14	1.020	5

TABLE No. 18

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 15—McKAY RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	2.9	91.5	5.6	2	19	31	48	1.025	..
2	5.7	89.7	4.6	....	7	52	41	1.020	..
3	5.4	89.0	5.6	....	28	49	23	1.020	..
4A	12.6	84.0	3.4	3	57	33	7	1.015	5
4B	7.3	85.9	6.8	4	9	47	40	1.025	..
5	9.3	86.6	4.1	....	4	31	65	1.020	5
6	1.3	86.6	12.1	6	10	19	65	....	..

DESCRIPTION OF STRATA No. 19

CROSS-SECTION No. 16—McKAY RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Lean, crumbly bituminous sand and shaley material......	9.2
1B	Lean, dry, crumbly, dark brown, cliff-forming bituminous sand	7.2
2A	Very lean, clayey material showing close lamination......	18.8
2B	Similar to 2A	14.5
3A,B	Alternating bands of bituminous sand and clayey material. At the top the bituminous sand bands are lean and the clay bands predominate; descending the bituminous sand becomes richer and predominates, but the clay bands are prominent throughout. Small poplar trees grow on the slope, and their roots penetrate the clay bands for 30 inches between bands of rich bituminous sand. The bituminous sand and clayey bands in this division were sampled separately. A was 15.4 ft. and B 24.4 ft.	39.8
4A	Hard, massive bituminous sand, free from clay...............	14.7
4B	Similar to 4A. This lens pinches out a short distance down stream	9.0
4C	Fairly soft, massive, rich, cliff-forming bituminous sand..	12.3
4D	Soft, rich, massive bituminous sand. This material may not be in place	9.9
	Total thickness of strata examined........	135.4

Three special samples were collected from 4C to test change in nature of the bituminous sand at various distances from the surface. First sample was collected in the hard, weathered material on the surface of the outcrop; the second sample was collected at a distance of 3 inches back from the surface, the distance reached by trench; the third sample was collected from the end of a drill hole 2½ feet in from the surface.

DESCRIPTION OF STRATA No. 20

CROSS-SECTION No. 17—McKAY RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Lean bituminous sand and shaley clay..............................	15.0
1B	Rich, homogeneous bituminous sand	14.1
2	Apparently rich bituminous sand, but the true nature of the beds is masked by extensive checking due to slight faults	23.5
	Total thickness of strata examined........	52.6

TABLE No. 19

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 16—McKAY RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25°/25° Cent.	Sulphur Content %
				48	100	200	200		
1A	1.1	85.3	13.6	40	12	26	22	....	..
1B	4.0	92.3	3.7	4	19	50	27	1.030	4
2A	1.7	85.9	12.4	2	10	13	75	....	..
2B	2.2	86.3	11.5	4	10	17	69	....	..
3A	10.0	84.7	5.3	1	5	60	34	1.030	..
*3A	2.9	86.7	10.4	14	10	29	47	....	..
3B	10.0	84.3	5.7	1	7	65	27	1.040	..
*3B	3.4	86.7	9.9	4	13	41	42	1.030	..
4A	10.0	87.3	2.7	....	24	65	11	1.050	5
4B	12.1	83.5	4.4	....	47	44	9	1.035	..
4C	12.8	84.8	2.4	1	48	45	6	1.030	5
4D	15.2	80.3	4.5	....	51	41	8	1.030	..
**	13.0	87.0	0.0	....	34	57	9	1.040	5
***	12.4	87.6	0.0	....	31	63	6	1.025	..
****	13.9	85.6	0.5	....	29	65	6	1.010	5

*Clay.
**From surface at 4C.
***Just below surface at 4C.
****From end of 2½-foot hole at 4C.

TABLE No. 20

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 17—McKAY RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25°/25° Cent.	Sulphur Content %
				48	100	200	200		
1A	4.9	87.5	7.6	14	17	47	22	1.060	..
1B	10.8	84.7	4.5	1	13	67	19	1.020	5
2	11.5	84.4	4.1	6	34	47	13	1.025	5

DESCRIPTION OF STRATA No. 21

CROSS-SECTION No. 18—ELLS RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Thin bands of lean bituminous sand in cliff formation. Material flakes off from the surface. Two 6-inch bands of sandstone occur at the bottom of the division and appear throughout the extent of the outcrop..................	16.2
2	Upper 5 feet consist of unstratified clay; beneath this clay is a 3-inch parting of hard, brown, woody lignite; beneath this lignite there are 5 feet of a more sandy, somewhat stratified clay; bottom 3 feet consist of heavy compact clay which breaks into rectangular chunks at the surface, but which is hard and intact back from the surface	10.9
3	Bituminous sand in cliff formation, much more laminated at the top than at the bottom. This bituminous sand has a peculiar nature compared to material elsewhere. Its brown color is too light in shade for bituminous sand of its apparent richness. Some freshly exposed surfaces are very rich in bitumen and make it appear as though the bitumen had seeped through the bituminous sand or had been concentrated in certain parts of the exposure by some agency such as water....	15.4
	Total thickness of strata examined........	42.5

DESCRIPTION OF STRATA No. 22

CROSS-SECTION No. 19—ELLS RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Lean, brown, stratified, cliff-forming bituminous sand....	12.5
2	Clay. The heavy, compact clay at the bottom of this division is not so prominent as in Cross-Section 18. A small layer of coal occurs in the clay one foot below the top of this division	12.9
2A	Lean, sandy bands of bituminous sand which fractures into rectangular chunks. These bands form a cliff........	17.1
3B	Fairly massive, rich, brown colored, cliff-forming bituminous sand	3.0
3C	Lean, wet, bituminous sand, containing one 6-inch band of fairly rich material	4.7
	Total thickness of strata examined........	50.2

TABLE No. 21

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 18—ELLS RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1	3.8	90.7	5.5	6	14	41	39	1.035	5
2	0.8	85.2	14.0	....	11	14	75	....	..
3	6.3	86.4	7.3	4	12	44	40	1.010	5

TABLE No. 22

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 19—ELLS RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1	0.4	89.0	10.6	2	15	46	37	....	..
2	1.4	85.8	12.8	....	12	13	75	....	..
3A	2.5	87.5	10.0	2	9	21	68	....	..
3B	9.4	84.9	5.7	....	5	56	39	1.005	4
3C	4.3	85.7	10.0	....	16	33	51	1.005	4

DESCRIPTION OF STRATA No. 23

CROSS-SECTION No. 20—ELLS RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Lean, light brown colored bituminous sand. The surface of the trench in this material had a greenish tinge..	6.5
1B	Brown colored bituminous sand, weathering to gray. Freshly broken surfaces sometimes gave the appearance of exceptionally rich material. This bituminous sand fractures in flakes ½ to 3 inches thick. The flakes are parallel to the face as if due to a creep of the material. Flakes 6 feet square are apt to break away from the surface	9.4
1C	Bands of variable material—sandy textured bituminous sand at the top changing into damp, clayey sand underlain by some fairly rich bituminous sand........	7.2
2	Clay	4.8
3A	Lean, laminated bituminous sand	8.2
3B	Fairly rich, rather closely laminated bituminous sand. A thin layer of a hard, red sandstone overlies these bands	7.1
	Total thickness of strata examined........	43.2

DESCRIPTION OF STRATA No. 24

CROSS-SECTION No. 21—ELLS RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Lean, closely laminated, brown bituminous sand........	11.5
1B	Variable bands of bituminous sand. The upper 2 feet are closely laminated; the next 5 feet are fairly massive, rich and cliff-forming; next 4 feet are closely laminated; bottom 6 feet are fairly massive and rich........	17.9
2	Fairly massive but laminated, lean bituminous sand. An 8-inch band of sandstone occurs 3½ feet from the top of this division and several other bands of hard, shaley material occur below the sandstone........	15.2
3A	Bands of cliff-forming bituminous sand about 18 inches thick. The bituminous sand fractures into thin flakes parallel to the face of the exposure. There is a 14-inch lens of clay toward the top of the division. The lens pinches out to the south along the exposure........	18.1
3B	Rather variable bituminous sand overlain by 2 feet of very hard material forming a ledge and with a 19-inch band of damp clay 4 feet from the bottom........	12.0
3C	Bituminous sand band 3 feet thick underlain by 3 feet of laminated clay, 4 inches of lean bituminous sand and 4 feet of wet, sandy clay	10.7
	Total thickness of strata examined........	85.4

TABLE No. 23

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 20—ELLS RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1A	2.7	92.4	4.9	2	13	56	29	....	..
1B	5.7	90.1	4.2	7	8	35	50	1.030	4
1C	2.0	87.3	10.7	....	10	14	76	1.010	..
2	1.0	83.8	15.2	....	10	11	79	....	..
3A	2.6	87.7	9.7	....	10	33	57	....	..
3B	11.5	85.2	3.3	1	7	58	34	1.015	4

TABLE No. 24

ANALYSES OF SAMPLES FROM
CROSS-SECTION No. 21—ELLS RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr 25° /25° Cent.	Sulphur Content %
1A	2.9	85.9	11.2	2	12	54	32	1.010	..
1B	7.0	87.6	5.4	3	12	43	42	1.005	4
2	1.7	86.4	11.9	2	13	14	71	1.020	..
3A	7.8	86.4	5.8	1	11	55	33	1.005	..
3B	7.1	86.0	6.9	2	14	44	40	1.005	5
3C	6.2	85.8	8.0	2	11	30	57	1.010	..

DESCRIPTION OF STRATA No. 25

CROSS-SECTIONS Nos. 22A, 22B, 22C—ATHABASKA RIVER

Cross Section	Division of Strata	DESCRIPTION	Thickness in Feet.
22A	1	Sand with little or no bitumen content. Two bands of sandstone occur, one near the top, the other near the bottom of this division	9.1
	2A	Black, cliff-forming bituminous sand	6.4
	2B	Black, cliff-forming, rather coarse grained bituminous sand. These bands are much weathered and broken into large chunks	4.1
	2C	Black, cliff-forming, very coarse grained bituminous sand. The weathered surface is covered with a fine white gravel	12.2
	3	Lean, cliff-forming bituminous sand, broken up into chunks, but not very hard. The weathered surface of some of these bands indicates a coarse sand. Partings of sulphur-colored material occur	10.2
	4	Soft, homogeneous bituminous sand. There is a shell of hard, weathered material on the surface	17.3
		Total thickness of strata examined	59.3
22B	1	Very hard, weathered bituminous sand	4.8
		Total thickness of strata examined	4.8
22C	1	Very coarse grained, hard bituminous sand	13.5
	2	Hard, dry bituminous sand, in two sections, one overlying and one underlying a 5½-foot band of clay. There is a band of clay 1 foot thick at the top of the division. The clay was not included in the sample	19.1
		Total thickness of strata examined	32.6

This series of exposures occurs on the East side of the river below McKay, one-half mile down stream from where the limestone makes its last appearance in an outcrop standing 30 feet above the river level. The bituminous sand exposures are much disturbed by slips, folding and creeping. Many bitumen seepages occur.

DESCRIPTION OF STRATA No. 26

CROSS-SECTION No. 23—MUSKEG RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Lean, laminated, bituminous sand. A one-half inch parting of coal occurs ten feet from the top of the division	25.6

TABLE No. 25

ANALYSES OF SAMPLES FROM

CROSS-SECTIONS Nos. 22A, 22B, 22C—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	100	200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
CROSS-SECTION 22A									
1	0.2	89.8	10.0	27	56	11	6	....	..
2A	5.0	91.9	3.1	2	62	27	9	1.060	..
2B	10.2	86.8	3.0	12	77	8	3	1.050	5
2C	6.4	90.0	3.6	36	59	3	2	1.065	..
3	6.3	89.6	4.1	19	71	7	3	1.025	4
4	10.7	82.9	6.4	20	68	7	5	1.025	..
Seepage 1	66.4	17.5	16.1	47	31	8	14	1.000	..
" 2	76.8	1.9	21.3	....	....	....	....	1.000	..
CROSS-SECTION 22B									
1	6.7	92.3	1.0	52	19	10	19	1.020	..
CROSS-SECTION 22C									
1	8.7	88.6	2.7	26	21	31	22	1.035	5
2	11.4	85.0	3.6	59	27	9	5	1.020	5

TABLE No. 26

ANALYSES OF SAMPLES FROM

CROSS-SECTION No. 23—MUSKEG RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	100	200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1	1.7	92.5	5.8	26	50	16	8	....	..

DESCRIPTION OF STRATA No. 27

CROSS-SECTION No. 24—ATHABASCA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Coarse grained, massive, rich bituminous sand. A few clay lenses occur near the top of the division.................	13.7
1B	Coarse grained, massive, uniform bituminous sand........	10.2
	Total thickness of strata examined........	23.9

DESCRIPTION OF STRATA No. 28

CROSS-SECTION No. 25—ELLS RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Hard, black, cliff-forming bituminous sand with pronounced fracture parallel to the face of the exposure....	21.0
1B	Alternating bands of rich and lean bituminous sand, differing markedly in appearance. The lean and the rich material were sampled separately	40.2
2	Lean, clayey, damp bituminous sand. Seven bands of sandstone from 3 to 8 inches thick were found distributed through the section of this division	44.0
3A	Alternating bands of rich bituminous sand and clay with no bitumen content, the bands increasing in thickness toward the bottom of the division. Only the bituminous sand was sampled; no clay was included in the sample....	30.5
3B	Very coarse grained, hard, dry, black, cliff-forming bituminous sand, forming the base of the bituminous sand exposure. This division was covered by talus at the cross-section, but was trenched to a depth of.................	5.0
	Total thickness of strata examined........	140.7

DESCRIPTION OF STRATA No. 29

CROSS-SECTION No. 26—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Rich, fairly soft, massive bituminous sand.....................	9.2

TABLE No. 27

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 24—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1A	9.4	83.6	7.0	69	15	8	8	1.040	5
1B	8.1	87.6	4.3	68	21	6	5	1.035	5

TABLE No. 28

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 25—ELLS RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1A	9.9	85.8	4.3	1	5	57	37	1.015	..
1B Rich ..	8.4	87.2	4.4	1	10	52	37	1.020	5
1B Lean ..	2.0	86.8	11.2	....	10	30	60	....	..
2	3.5	85.4	11.1	....	14	28	58	1.010	5
3A	13.6	83.2	3.2	3	15	68	14	1.010	5
3B	9.4	87.3	3.3	28	44	18	10	1.010	5

TABLE No. 29

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 26—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	13.6	83.2	3.2	2	11	67	20	1.030	..
*Special	....	......	......	10	84	4	2	....	..

*Sample from the cliff down the river from the cross-section.

DESCRIPTION OF STRATA No. 30

CROSS-SECTIONS Nos. 27A, 27B, 27C—ATHABASKA RIVER

Cross Section.	Division of Strata.	DESCRIPTION.	Thickness in Feet.
27A	1	Hard, massive, cliff forming bituminous sand. Although the actual surface material was removed the material as sampled has been affected by weathering	17.2
		Total thickness of strata examined	17.2
27B	1	The cross-section was continued through 1B at a point 85.7 feet south of 1A, due to the large amount of talus that had collected at the base of 1A. 1B massive, rich, fairly coarse bituminous sand	15.5
		Total thickness of strata examined	15.5
27C	1	Soft, rich, wet, fairly massive bituminous sand	22.2
		Total thickness of strata examined	22.2

Since no one location gave opportunity for examination of the entire thickness of strata of this series of exposures, three cross-sections were made. Cross-section 27B is off-set about 85 feet from 27A, but follows immediately below it in the matter of succession of beds. The lowest point in 27A was traced along the stratification up a decided dip to the location of 27B. Cross-section 27C is 100 yards on the other side of 27A and the intervening formation is concealed. Because of the downward dip evident at 27A, 27C may represent lower strata than shown in 27B.

DESCRIPTION OF STRATA No. 31

CROSS-SECTIONS Nos. 28, 29, 30—ATHABASKA RIVER

Cross-Section.	Division of Strata.	DESCRIPTION.	Thickness in Feet.
28	1A	Closely laminated, lean bituminous sand	7.2
	1B	Commences with 9 inches of sandstone, underlain by a band of lean and a band of rich bituminous sand, followed by a massive clay band of a blue color	12.5
		Total thickness of strata examined	19.7
29	1A	Lean, bituminous sand with an irregular fracture; 9-inch band of sandstone about the centre of this division	17.6
	1B	Fairly rich, cliff-forming bituminous sand, many very thin lenses of clay, the majority of which lie to the north of the cross-section. The bottom of the division is of a shaley nature	11.6
		Total thickness of strata examined	29.2
30	1	Fairly hard bituminous sand with a rectangular fracture. Two thin, lean, brown bands of bituminous sand indicate the presence of an iron oxide. Near the bottom the division is more closely laminated and there are a few bands of shale	9.6
		Total thickness of strata examined	9.6

Low bituminous sand exposures occurring along the Athabaska river between Tar river and Wheeler's Point.

TABLE No. 30

ANALYSES OF SAMPLES FROM

CROSS-SECTIONS Nos. 27A, 27B, 27C—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25° /25° Cent.	Sulphur Content %
				48	100	200	200		
CROSS-SECTION 27A									
1	11.4	87.4	1.2	6	16	63	15	1.035	..
CROSS-SECTION 27B									
1	11.4	85.3	3.3	3	12	65	20	1.020	..
CROSS-SECTION 27C									
1	11.3	84.5	4.2	2	11	63	24	1.020	.5

TABLE No. 31

ANALYSES OF SAMPLES FROM

CROSS-SECTIONS Nos. 28, 29, 30—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh			Passing Mesh	Sp. Gr. 25° /25° Cent.	Sulphur Content %
				48	100	200	200		
CROSS-SECTION No. 28									
1A	4.7	89.3	6.0	15	14	44	27	1.045	..
1B	5.9	90.1	4.0	4	10	48	38	1.035	5
CROSS-SECTION No. 29									
1A	8.4	89.0	2.6	2	19	61	18	1.035	5
1B	8.8	86.6	4.6	....	3	49	48	1.025	5
CROSS-SECTION No. 30									
1	7.6	86.6	5.8	4	11	41	44	1.035	5

DESCRIPTION OF STRATA No. 32

CROSS-SECTION No. 31—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Bituminous sand in bands from 6 to 24 inches thick, hard and weathered, especially at the top	9.5
1B	Soft, massive bituminous sand in bands about 1 foot thick	8.1
2	Fairly rich bituminous sand bands interbedded with lean bituminous sand and clay partings. A 6-inch layer of clayey shale occurs 4½ feet from the bottom of the division	16.6
3A	Hard, lean, dry, cliff-forming bituminous sand	2.9
3B	Black, dry bituminous sand. The upper half is stratified into bands 12 to 18 inches thick. The lower part is covered by talus and confused by slips. A trench 3 feet deep was dug to bring these bands to view	19.2
3C	Fairly soft, massive, homogeneous bituminous sand. An off-set trench was dug to examine these bands	12.0
	Total thickness of strata examined	68.3

DESCRIPTION OF STRATA No. 33

CROSS-SECTION No. 32—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Rich, massive, bituminous sand; at the top it appears dry. The surface is weathered hard, but back from the surface the material is quite soft	14.9
2	Rich, wet, massive, fairly soft bituminous sand	20.8
3	Very similar to No. 2	5.0
4	Similar to Nos. 2 and 3, but more inclined to withstand erosion. Many small nodules of marcasite occur in this division	11.6
	Total thickness of strata examined*	52.3

*This outcrop represents an area of considerable size, over which the overburden is 10 feet or less, and is covered mainly by a tamarac and spruce swamp.

DESCRIPTION OF STRATA No. 34

CROSS-SECTION No. 33—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Alternating bands of wet, fairly rich bituminous sand and bands of clay. A two-inch parting of limey clay forms the base of this division	11.4
2A	Fairly rich bituminous sand, with an irregular fracture. Two bands of shale occur and in each case the underlying band of bituminous sand is very hard at the top and becomes softer towards the bottom of the band	2.2
2B	Rich, uniform, soft, cliff-forming bituminous sand. Surface hard but material underneath quite soft	11.5
	Total thickness of strata examined	35.1

TABLE No. 32

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 31—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1A	10.0	87.2	2.8	3	13	63	21	1.040	..
1B	11.9	84.2	3.9	2	15	59	24	1.015	5
2	7.1	86.9	6.0	6	12	37	45	1.025	..
3A	6.3	90.8	2.9	3	69	20	8	1.030	..
3B	7.0	89.9	3.1	22	61	12	5	1.025	5
3C	9.5	86.4	4.1	24	57	13	6	1.030	..

TABLE No. 33

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 32—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1	12.5	84.3	3.2	....	5	84	11	1.025	..
2	11.8	82.8	5.4	....	9	83	8	1.020	5
3	12.8	80.8	6.4	....	9	80	11	1.025	..
4	12.5	84.4	3.1	....	3	87	10	1.020	5
Pits	5.8	87.9	6.3	....	3	83	14	....	..

TABLE No. 34

ANALYSES OF SAMPLES FROM CROSS-SECTION No. 33—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25°/25° Cent.	Sulphur Content %
1	7.1	86.6	6.3	29	15	41	15	1.035	..
2A	9.0	86.9	4.1	6	23	58	13	1.050	..
2B	12.9	80.6	6.5	....	19	66	15	1.020	..

DESCRIPTION OF STRATA No. 35

CROSS-SECTION No. 34—ATHABASKA RIVER

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1	Black, dry, cliff-forming bituminous sand, hard but softens in the sun	16.2
2	Soft, massive bituminous sand. Bottom part of the division is cliff-forming. Thin partings of lignite were noted in places	16.8
3A	Soft, massive, cliff-forming bituminous sand........	7.7
3B	Similar to 3A	12.2
	Total thickness of strata examined........	52.9

DESCRIPTION OF STRATA No. 36

CROSS-SECTION No. 35—PRAIRIE CREEK

Division of Strata.	DESCRIPTION.	Thickness in Feet.
1A	Lean, medium grained, cliff-forming bituminous sand, having a crumbly nature. Cross-bedding is verp apparent in the lower five feet of this division........	10.0
1B	Fairly rich, rather fine textured, dry bituminous sand, weathered to a hard surface, but back from the surface the material is fairly soft. Towards the base of this division there are several small partings of lignite and of clay	29.6
	Total thickness of strata examined........	39.6

TABLE No. 35

ANALYSES OF SAMPLES FROM

CROSS-SECTION No. 34—ATHABASKA RIVER

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1	8.6	91.0	0.4	4	77	15	4	1.020	..
2	12.2	86.5	1.3	1	77	15	7	1.030	4
3A	14.0	83.1	2.9	9	68	17	6	1.025	..
3B	13.2	84.0	2.8	....	39	55	6	1.025	..
*Special	....	....	....	1	34	55	10	....	..

*White sand overlying the bituminous sand at the cross-section.

TABLE No. 36

ANALYSES OF SAMPLES FROM

CROSS-SECTION No. 35—PRAIRIE CREEK

Division of Strata	Composition of Sample Per cent. of			Screen Analysis of Mineral Matter Per cent.				Character of Bitumen	
	Bitumen	Mineral Matter	Water	Retained on Mesh 48	Retained on Mesh 100	Retained on Mesh 200	Passing Mesh 200	Sp. Gr. 25° /25° Cent.	Sulphur Content %
1A	9.1	89.3	1.6	24	66	8	2	1.050	..
1B	12.9	84.7	2.4	8	67	20	5	1.040	..

ANALYSES OF COAL SAMPLES

A number of outcrops of coal were encountered while examining the outcrops of bituminous sand. Those of chief significance were on the upper Athabaska, Christina, Steepbank and McKay rivers. One such occurrence in each of the latter three areas was sampled for analysis.

Coal of good quality and in commercial quantities in the bituminous sand area would be of importance. But unfortunately, though lignite is fairly generally associated with the bituminous formation, the quantities are rather insignificant, the quality poor and the mode of occurrence such as to make the mining of it almost impossible.[29]

The coal is found in the form of bands, usually lenticular in form, underlying the bituminous sand formation. The coal is usually overlain by shale and minor bands of coal. In some cases, however, it is overlain directly by the bituminous sand. The bands in some cases are underlain by a small amount of shale and clay, which, in turn, overlies the limestone; and in other cases the coal rests directly on the limestone.

The bands of coal sampled were in each case at least two feet in thickness and the outcrops were traced for at least 100 feet.

There are numerous outcrops of coal along the Christina river. The bands vary in thickness from a few inches to about four feet. The following analysis[30] is of a channel sample from an outcrop occurring near cross-section No. 7. This particular occurrence is overlain by bituminous sand and underlain by shale.

Location: Tp. 88, Rg. 6, W. 4th Mer. Sampler S. M. Blair.

Method of Air-Drying: Standard. Loss on Air-Drying: 13.9%.

Proximate Analysis:	As Received.	Air-Dried.	Dried.
Moisture ....%	28.0	16.4	......
Ash ....%	16.1	18.6	22.3
Volatile Matter ....%	25.1	29.2	34.9
Fixed Carbon ....%	30.8	34.8	42.8
Calorific Value, gross: B.T.U. per lb.	7,070	8,210	9,820
Fuel Ratio (Fixed Carbon/Volatile Matter)	....	1.20	......

There are numerous outcrops of coal along the McKay river. The following analyses are of channel samples taken from two bands of coal each two feet in thickness. The bands are separated by one foot of clay. They are overlain by bands of clay containing minor bands of coal and underlain by four feet of clay which overlies the limestone.

Location: Tp. 96, Rg. 11, W. 4th Mer. Sampled 11th Aug. 1924, by G. J. Knighton.

Upper Band of Coal.

Method of Air-Drying: Standard. Loss on Air-Drying: 6.1%.

Proximate Analysis:	As Received.	Air-Dried.	Dried.
Moisture ....%	14.2	8.6	......
Ash ....%	33.6	35.8	39.2
Volatile Matter ....%	24.5	26.1	28.6
Fixed Carbon ....%	27.7	29.5	32.2
Calorific Value, gross: B.T.U. per lb.	6,620	7,050	7,710
Fuel Ratio (Fixed Carbon/Volatile Matter)	....	1.15	......

29cf. Bituminous Sands of Northern Alberta, S. C. Ells, Mines Branch, Dept. of Mines, Canada, No. 632, 1926, p. 166. "A tunnel was driven by A. Hammerstein for more than 20 feet on a seam of lignite outcropping on the east bank of Athabaska river. . . . . As is usual with coal seams in the McMurray area, roof and floor were unstable, and in spite of fairly secure timbering, the tunnel collapsed within a comparatively short time."

30The coal analyses were made by W. P. Campbell, Fuel Analyst. The "Standard" method of air-drying consists of allowing the coal sample to dry in air maintained at 60% humidity (cf. 4th Annual Report Scientific and Industrial Research Council of Alberta, p. 39).

Lower Band of Coal.

Method of Air-Drying: Standard. Loss on Air-Drying: 6.8%

Proximate Analysis:	As Received.	Air-Dried.	Dried.
Moisture ....%	16.6	10.5	......
Ash ....%	14.9	16.0	17.9
Volatile Matter ....%	31.4	33.7	37.6
Fixed Carbon ....%	37.1	39.8	44.5
Calorific Value, gross: B.T.U. per lb.	8,600	9,230	10,300
Fuel Ratio (Fixed Carbon/Volatile Matter)	....	1.20	......

There are fewer occurrences of coal in the Steepbank area than along the Christina or McKay rivers. The following analysis is of a channel sample of a band of coal three feet thick. The outcrop shows in Cross-section No. 14. This band is overlain by bituminous sand, and is underlain by the limestone.

Location: Tp. 92, Rg. 9, W. 4th Mer. Sampled 2nd Aug., 1924, by G. J. Knighton.

Method of Air-Drying: Standard. Loss on Air-Drying: 1.4%.

Proximate Analysis:	As Received.	Air-Dried.	Dried.
Moisture ....%	12.4	11.2	......
Ash ....%	25.3	25.7	28.9
Volatile Matter ....%	25.3	25.7	28.9
Fixed Carbon ....%	37.0	37.4	42.2
Calorific Value, gross: B.T.U. per lb.	7,770	7,880	8,870
Fuel Ratio (Fixed Carbon/Volatile matter)	....	1.45	......

CHAPTER IV.

DISCUSSION OF RESULTS.

The bituminous sand exposures in Northern Alberta offer what is probably a unique opportunity for examination of a type of extensive oil-sand formation. While they differ, in nature and in conditions of occurrence, from petroleum-producing formations, there must be many features of similarity. It is hoped that the descriptions of strata observed in the bituminous sand exposures and the analyses of material from these strata will be useful to those studying the methods of occurrence of petroleum as well as to those interested in the Alberta bituminous sands. The tables of data contain much that is suggestive and will bear more study than that represented by the discussion which follows.

Variations in Bitumen Content.

The wide variation of bitumen content of the bituminous sands presents an interesting study. Samples examined showed percentages of bitumen ranging from one or two per cent. to a maximum of about seventeen and one-half per cent. It is of both practical and theoretical interest to attempt to determine the various factors which have been responsible for the varying degrees in which the beds of the formation have been impregnated with bitumen. The data contained in the descriptions of strata and tables of analyses provide a good background for a consideration of this question.

(*a*) *The Gravity Factor.*

It is reasonable to suppose that the force of gravity would be a factor in the distribution of the bitumen through the sands, and such is found to be the case. The descriptions of strata contain frequent notes of observations that the material appeared leaner toward the top, or richer toward the bottom of bituminous sand beds. Where the sand is well impregnated, the bitumen tends, to a certain extent, to settle down on some impervious layer, such as a parting of clay. On the surfaces of a fresh exposure small dribbles of bitumen are often found coming from the contact between such partings and rich bituminous sand. The description of cross-section No. 13, page 34, contains illustrations of the sort of observations that are referred to.

The analyses contain some striking illustrations of the effect of gravity on the bitumen content of series of strata of uniform nature. Attention is directed to the analytical data for cross-section No. 2, page 19, Stratas 4, 5A, B, C, D; cross-section No. 13, page 35, Stratas 4A, B, C, D; cross-section No. 16, page 39, Stratas 4A, B, C, D. In each of these cases there is a thickness of over forty-five feet of bituminous sand of fairly uniform texture, and an ideal condition has occurred for gravity to influence the distribution of the bitumen.

(*b*) *The Factor of Coarseness of the Impregnated Sand.*

The size of the sand particles has been a factor, though not a major one, influencing the bitumen content of bituminous sand. Other conditions being similar, a coarse grade of bituminous sand will have a lower bitumen content than a fine grained one. It would appear that the bitumen present in bituminous sand bears a much closer relationship to the surface of the sand grains than to the spaces between them. On this assumption, it follows that a fine sand with its larger area of surface can hold more bitumen than a coarse sand.

TABLE No. 37

THE EFFECT OF COARSENESS OF SAND GRAINS ON THE BITUMEN CONTENT OF BITUMINOUS SANDS

A selected number of analyses showing that a coarse bituminous sand is not the type richest in bitumen, and that the richest material contains a fine sand.

Cross-section and Division of Strata	Composition of Sample			Screen Analyses of Mineral Matter			
	Bitumen %	Mineral Matter %	Water %	% Retained on Mesh 48	100	200	Passing Mesh 200
Well impregnated bituminous sand samples with more than 15% of sand particles retained on 48 mesh sieve.							
No. 3-5B	10.7	87.3	2.0	37	40	16	7
-8C	12.6	86.6	0.8	23	63	9	5
No. 6-1	12.1	87.7	0.2	18	52	25	5
-3	9.7	88.4	1.9	78	13	5	4
No. 22C-2	11.4	85.0	3.6	59	27	9	5
No. 24-1A	9.4	83.6	7.0	69	15	8	8
No. 25-3B	9.4	87.3	3.3	28	44	18	10
No. 31-3C	9.5	86.4	4.1	24	57	13	6
No. 35-1A	9.1	89.3	1.6	24	66	8	2
Bituminous sand samples containing 15% bitumen, or more.							
No. 1-7A	15.1	83.8	1.1	....	39	53	8
-7B	15.1	84.4	0.5	....	51	43	6
No. 2-5C	15.5	83.7	0.8	1	57	35	7
-5D	17.4	82.2	0.4	....	27	65	8
Shaft	16.0	81.9	2.1	....	57	38	5
No. 5A-1A	17.4	82.1	0.5	....	41	51	8
-1B	16.1	81.5	2.4	....	46	44	10
No. 5B-	16.8	82.9	0.3	....	47	48	5
No. 16-4D	15.2	80.3	4.5	....	51	41	8

The factor of coarseness of sand can be demonstrated by means of the analyses. This is done best by restricting attention to samples of bituminous sand which contain a bitumen content of at least nine per cent. Much of the effect of interference of more important factors is avoided in this way. Considering only such samples, it is found that all bituminous sands with sand containing more than 15% of particles retained on the 48 mesh have relatively low bitumen contents; while all samples containing bitumen in excess of 15% are those with sand particles distinctly fine grained. These data are compiled in Table No. 37. It may be noted that all these rich bituminous sands occur in such a way as to be influenced by the factor of gravity. But the same condition applies to the coarse grained bituminous sands considered. In fact, if a more extended review is made of all the data presented, it will probably be concluded that none of the coarse grained bituminous sands would have had a bitumen content as great as 9% if the factor of gravity had not caused their enrichment.

That coarse grained bituminous sands are not the ones richest in bitumen is an observation that applies to more deposits than those in Alberta. Quarrymen in the Kentucky asphalt rock quarries have learned by experience that coarse varieties of rock are lean in spite of their appearance of richness. In the bituminous sand deposit near Santa Cruz, California, a coarse and a fine grained type of material are excavated. The finer grained variety contains considerably more bitumen than the coarser one.

(*c*) *Water, and Clay or Silt Factors.*

The outstanding factor responsible for the wide variation in bitumen content of bituminous sands is water. And closely associated with water is the silt or clay content of the various beds of the bituminous sand formation. There is no escaping the conclusion that low bitumen contents are due to the effect of water and that high water content in bituminous sand beds is intimately associated with the presence of silt and clay. But the exact relationship of water, silt and bitumen content is not so obvious. However, the data presented provide material for interesting observations and speculations.

The tables of analyses are full of illustrations of the influence of water and silt on the content of bitumen. If the low figures are noted in the columns in which the percentages of bitumen in the samples are recorded, it will generally be found that corresponding to the low bitumen content there is a high content of water and of mineral matter passing the 200 mesh sieve. The main exceptions will be found with top beds which have been altered by weathering.

One is confronted with a series of questions on attempting a consideration of the part that water has played in influencing the bitumen content of the bituminous sand, and in bringing about present conditions at the surfaces of exposures. Were the beds of sand with their varying silt and clay contents free from water at the time the oil entered them? Did the water now present come in subsequent to the oil and expel some of it? Or was the original deposit wet and especially wet where there was a high content of silt and clay? Did the oil fail to displace the water from the wet clay and consequently fail to impregnate sand beds in proportion to the degree in which wet silt or clay were present? And does the condition observed at the face of exposures extend throughout the beds, or is it merely a local effect? It is interesting to seek for some light on such questions.

Bitumen seepages provide a possible starting point for consideration of the effect of water in influencing bitumen content. Seepages are found at a number of points in the central part of the area. These seepages are always associated with water and appear to be due to water working through the bituminous sand and carrying bitumen out of the beds. Some samples of seepage bitumen were collected and examined. Results of their examination appear in the analytical data for cross-sections Nos. 13, page 35, and 22A, page 45. These show that in each case the seepage bitumen contains approximately 20% of water.

One explanation of the action that takes place at a seepage is as follows. Water, on entering a thoroughly impregnated bituminous sand bed, is first absorbed by the bitumen and a water-in-oil emulsion results. This absorption continues till the bitumen takes up one-quarter of its weight of water, or, in other words, until a bitumen emulsion containing 20% of water is formed. More water can enter the bituminous sand only by displacing from it an equal volume of bitumen emulsion.

This way of regarding the influence of water on the bitumen to form seepages may be applied to bituminous sand beds in general with interesting results. It provides a method of calculating the bitumen equivalent of the water found to be present in bituminous sand. If there was thorough impregnation originally, and water entered and displaced bitumen, the original bitumen content can be figured by correcting for the water now found present. If, on the other hand, the water now found was originally present, and prevented thorough impregnation, the same method of figuring gives what the bitumen content would have been if the bitumen had succeeded in displacing the water and thoroughly impregnating the sand. These calculated bitumen contents should be approximately the same as the bitumen content of the well impregnated bituminous sand now present in the formation, if either of the above ways of regarding the role of water is valid.

The anlyses for cross-sections Nos. 3, page 21, 14A, page 35, and 20, page 43, will be examined in some detail, making use of this method for calculating the bitumen equivalent of water. It will be noted that the sections selected show marked variation in bitumen content, and content of water and silt throughout the strata. They are sections which extend well through the formation. And they are located at widely separated points throughout the bituminous area. All three exposures are decidedly lean. Yet Nos. 3 and 14A are only a mile or so away from exposures showing exceptional thicknesses of high grade material.[31]

A set of theoretical bitumen contents corresponding to the percentages of bitumen and water found by actual analyses of samples from cross-sections Nos. 3, 14A, and 20 (cf. Tables Nos. 3, 16 and 23)

[31]At cross-sections Nos. 1 and 2 and the shaft on Horse river, and cross-section No. 13 on Steepbank river.

are given in Table No. 38. The method of calculating these theoretical values is as follows:

Let b=gms. of bitumen found by analysis in 100 gms. of bituminous sand.

w=gms. of water found by analysis in 100 gms. of bituminous sand.

m=gms. of mineral matter found by analysis in 100 gms. of bituminous sand.

Then $\frac{b}{4}$ =gms. of water that b gms. of bitumen has absorbed in the form of a water-in-oil emulsion.

and $w-\frac{b}{4}$ =gms of water present which is in excess of what the b gms. of bitumen has absorbed.

If the water entered the bituminous sand subsequent to the entry of the bitumen, it is assumed that it did so by first forming an emulsion with the bitumen present and that more water than what the bitumen could emulsify got in only by dsiplacing an equal volume of water-in-oil emulsion. Therefore, neglecting the slight difference in density between water and water-in-oil emulsion,

$\frac{4}{5}\left(w-\frac{b}{4}\right)$=gms. of bitumen which the excess water displaced from the m gms. of mineral matter.

and $b+\frac{4}{5}\left(w-\frac{b}{4}\right)$ =gms. of bitumen originally present in the m gms. of mineral matter before the water entered.

If the water was present in the mineral matter originally, and the bitumen entered subsequently, it is assumed that the bitumen absorbed the water it met up to its absorption capacity and that water in excess of what could be absorbed, blocked further entry of bitumen. On this assumption

$b+\frac{4}{5}\left(w-\frac{b}{4}\right)$=gms. of bitumen which would have been present in m gms. of mineral matter if excess water had not prevented its entry.

$$b+\frac{4}{5}\left(w-\frac{b}{4}\right)=\frac{4}{5}(w+b)=X_1$$

Let X=per cent. of bitumen that was originally present in m gms. of mineral matter, or would have been present if the water had not prevented its entry,

$$\text{Then } X=\frac{100\,X_1}{X_1+m}$$

If w is equal to, or less than $\frac{b}{4}$, impregation of the mineral matter has been complete, according to the assumptions made. If the water entered subsequent to the bitumen, it was all absorbed by the bitumen. If the bitumen entered subsequent to the water, it absorbed all the water it found present. In such cases

$$X_1 = b$$

TABLE No. 38

THE EFFECT OF WATER ON THE BITUMEN CONTENT OF BITUMINOUS SANDS

This table is a theoretical revision of Tables Nos. 3, 16 and 23. The values of bitumen contents have been calculated from the corresponding analytical data by the method described on page 60. The table gives what the analyses (on a dry basis) of samples from the strata of cross-sections Nos. 3, 14A and 20 would have been if water had not interfered with their impregnation.

Division of Strata	Composition of Theoretical Samples Per cent. of		Screen Analyses of Mineral Matter Per cent.			
	Bitumen	Matter Mineral	Retained on Mesh			Passing Mesh
			48	100	200	200
CROSS-SECTION No. 3						
1A	3.2	96.8	....	18	76	6
1B	5.4	94.6	....	12	61	27
2	9.7	90.3	....	22	49	29
3	10.0	90.0	....	28	51	21
4	13.2	86.8	....	27	64	9
5A	11.3	88.7	7	40	34	19
5B	10.9	89.1	37	40	16	7
6A	10.6	89.4	1	20	40	39
6B	10.2	89.8	1	23	46	30
7	12.5	87.5	....	20	29	51
8A	3.3	96.7	16	76	6	2
8B	8.7	91.3	18	73	6	3
8C	12.7	87.3	23	63	9	5
CROSS-SECTION No. 14A						
1A	5.9	94.1	1	17	52	30
1B	6.8	93.2	7	8	47	38
1C	11.2	88.8	5	5	34	56
2	12.7	87.3	1	14	60	25
3	11.3	88.7	1	16	69	14
4A	12.7	87.3	....	15	72	13
4B	14.6	85.1	....	24	68	8
4C	9.7	90.3	26	23	37	14
4D	6.2	93.8	42	44	9	5
CROSS-SECTION No. 20						
1A	6.2	93.8	2	13	56	29
1B	8.1	91.9	7	8	35	50
1C	10.5	89.5	....	10	14	76
2	13.5	86.5	....	10	11	79
3A	10.1	89.9	....	10	33	57
3B	12.2	88.8	....	7	58	34

It is seen that in the main the theoretical bitumen contents fall reasonably consistently within the range from 10 to 14%. This range is comparable to that shown by the well impregnated bituminous sands of the formation.[32] This result makes it appear that the view that has been taken regarding the action of water in removing bitumen from impregnated sand or in inhibiting the entrance of bitumen is essentially correct.

The inconsistent values for theoretical bitumen contents are as interesting and as important as the others. They give a strong indication of the answer to the questions of whether the water has driven bitumen from impregnated beds or has prevented their impregnation, and as to whether the conditions observed at an exposure are local or extend in a general way through the body of the formation. It will be observed that all low theoretical bitumen contents occur in connection either with the beds at the top of the formation or with beds of coarse grained sand relatively free from silt. What has probably happened is that water has entered such beds subsequent to the original impregnation and has displaced bitumen, but that much of the water which did the displacing has also gone. The conditions which affected the beds at the top of the formation have, no doubt, undergone many changes, but their effect can reasonably be regarded as localized in the top beds. Beds of coarse sand with small content of silt would be the beds most easily penetrated by water working its way through the formation. This water would displace bitumen from the coarse sand. But when the flow of water ceased, the water that was present in the coarse sand would drain away and neither the total original bitumen nor the water equivalent of the bitumen that disappeared would now be found present in the sand. This effect of water in coarse sand would also be local, depending on the extent of the flow of water and the opportunity presented for both water and bitumen to get away from the bituminous sand at some outcrop. The bitumen seepages that are observed at various points in the bituminous formation today are in all probability examples of this action of water working to a surface through an open-grained bituminous sand and bringing bitumen with it. The same action has no doubt taken place, under the influence of a different set of local water conditions, at many places other than where it can be seen today.

It is hard to conceive of the deposits of sandy and clayey beds being dry prior to impregnation with bitumen. It is much more reasonable to suppose that these beds contained much the same water content they are now found to possess. Oil entering beds relatively free from silt and clay would absorb the comparatively small amount of water that was held on the sand surfaces and would thoroughly impregnate these beds. But in the case of silty and clayey beds holding a comparatively large quantity of water, the migrating oil would find more water than it could absorb and would fail to completely impregnate the beds in proportion to this excess water. The oil would work its way over the surfaces of the

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[32] cf. range of bitumen contents of normally well impregnated sand given on page 64.

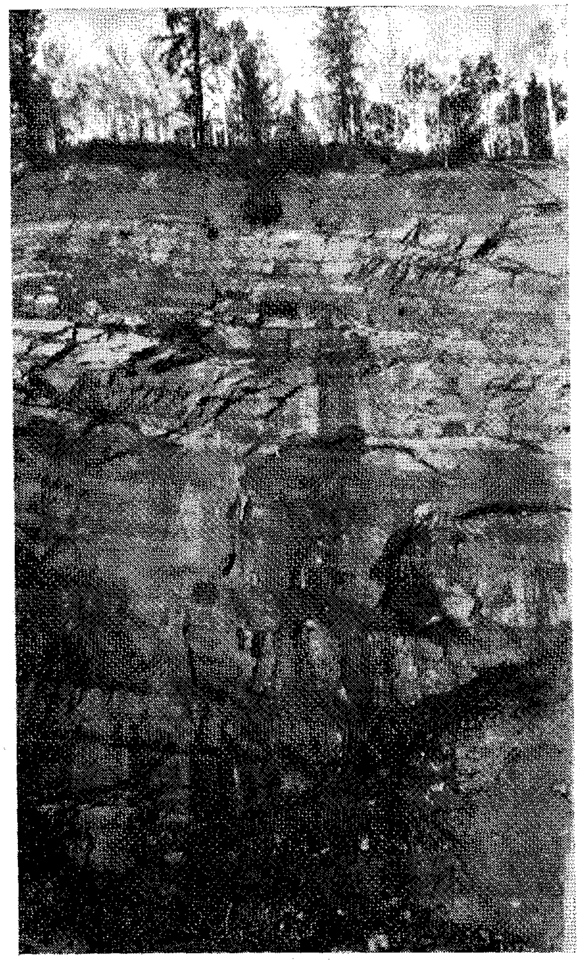

PLATE VI.—Bituminous Sand Exposure at Cross-Section No. 13, Steepbank River.

sand particles, but would fail to absorb or displace the water from the wet silt and clay, and would fail to become intimately associated with the latter.

It follows from the theory that has been developed for the action of water and also from the discussion of the other factors which influence bitumen contents that the examination of samples from exposures gives the true composition of the corresponding bituminous sand beds. The operation of all these factors in independent of proximity to exposures. Direct evidence supporting this conclusion is provided by the examination of samples from the shaft and from neighboring exposures in Horse river valley.[33] The compositions of these samples are in essential agreement.

The controlling factor in the distribution of bitumen throughout the bituminous formation is the occurrence of silt and clay and its associated water. Because of this it is interesting and important to study the distribution of silt and clay through the various strata, although nothing very definite can be concluded. If the tables of analyses are considered together with the information given in the descriptions of strata as to the position of the beds in question in the total section of the formation, there can be observed a general tendency for the smaller silt contents to occur in the lower beds. And coincident with this tendency, it is the lower beds that are most consistently composed of rich bituminous sand. But this tendency cannot be counted upon. Apparently the sedimentation conditions at the time of deposition of the original sand formation were most erratic and resulted in the laying down of a confused jumble of lenticular beds of material which varied quickly, both laterally and vertically, in the matter of grading of mineral particles. And although there is the tendency mentioned for lower beds to be comparatively free from silt and clay and to be rich in bitumen, and upper beds to be of high silt content and lean in bitumen, there is no guarantee that at a given location it will not be found that lean silty beds persist right through the strata to the bottom of the formation, or that the whole thickness of beds will not be composed of rich, well impregnated material. Very dissimilar conditions are found in close proximity. Examples have been already mentioned in the contrast between exposures on Horse and Hangingstone rivers, and between exposures 13 and 14A on Steepbank river.

(*d*) *Summary of Indications Regarding Variations in Bitumen Contents.*

The following conclusions are offered by way of a summary of the discussion of the variations in bitumen content of bituminous sand, and the factors responsible for these variations:

(1) The bitumen content of normally well impregnated bituminous sand beds falls between the approximate limits of 10.5%

[33]Compare the analyses of shaft samples with those of samples from cross-section No. 2, strata 5C and D, and from cross-sections Nos. 5A and B.

and 13.5%. Bitumen contents greater than 13.5% are abnormally high and are to be accounted for by some special condition. Bitumen contents less than 10.5% are low, because of some special condition, or because of the intervention of some factor which has interfered with complete impregnation.

(2) The force of gravity causes the lower part of otherwise uniform[34] beds of bituminous sand to be richer in bitumen than the upper part. Bitumen contents in excess of 13.5% are accounted for in most cases by the action of gravity. Large tonnages of bituminous sand containing 15% or more of bitumen will be found only where sufficient thickness of uniform, well impregnated strata exist, or have existed, to lead to abnormal concentration of bitumen in a considerable depth of the bottom bituminous sand beds.

(3) Other conditions being the same, a fine grained bituminous sand will contain more bitumen than a coarse grained one. The largest bitumen contents are found under conditions where fine grained sand occurs at the bottom of uniform beds of material, and where gravity has assisted in the impregnation.

(4) The presence of water, associated with silt or clay, in the original deposit was the outstanding factor influencing the degree of impregnation of the various beds with bitumen. The incoming bitumen was able to absorb the small amount of water present on the surfaces of sand grains and to coat them over, but was unable to absorb or expel the relatively large amount of water held by the silt and clay and come into intimate association with it.

(5) Water has entered some beds of the bituminous formation subsequently to the original impregnation, and has altered the bitumen content. The ones affected in this way are mostly surface beds and beds of open texture, comparatively free from clayey matter. This action of water has been of limited extent, has been due to local conditions, and has been comparatively unimportant. Bitumen seepages are the result of this sort of water action taking place at the present time.

(6) There is a general tendency for the upper beds to be the silty ones, and for the silt content to become less toward the lower part of the formation. This point has practical significance, since it has resulted in the corresponding general condition that the principal beds of rich bituminous sand occur low down in the formation.

(7) The analyses of samples of bituminous sand collected from beneath the surface weathering at exposures give a true picture of the composition and degree of impregnation of the bituminous sand beds. There is no reason to suppose, however, that conditions found to be true of the beds at the location of the exposure persist unchanged laterally away from that location. The bituminous formation is built up of a haphazard arrangement of lenticular beds, and rapid lateral variation is one of its principal characteristics.

34By uniform beds in this and the following paragraph is meant beds of uniform sedimentation unbroken by layers of clay or silt.

Variations in Specific Gravity.

The specific gravities of bitumen contents of the bituminous sand samples show a wide range of variation, the significance of which calls for discussion. Most of the variation appears to be due to local conditions which affect material lying close to the faces of exposures or occurring in top, weathered, bituminous sand beds. Nevertheless, from the numerous values determined, and from information given by other data, there is definite indication that important variations exist in the specific gravity of the bitumen present in the body of different sections of the deposit.

The results of the examination of samples collected from the shaft on Horse River (see page 25) in comparison with those from neighboring exposures, are of importance in discussing the meaning of the specific gravity values. It will be observed that the specific gravity of the bitumen in all shaft samples, excepting the two lowest ones, is 1.020. The strata penetrated by the shaft correspond to the lower strata of cross-sections Nos. 1 and 2 (pages 17, 19), and to those seen in cross-sections Nos. 5A and B (page 25). And the specific gravities of the bitumens contained in samples collected from these corresponding strata at exposures are, in all cases, 1.025. It thus appears that the specific gravity of the bitumen in bituminous sand lying well back from an exposure, such as that penetrated by the shaft, is somewhat less than corresponding bitumen close to an exposure. It should be noted, further, that cross-sections Nos. 1, 2, 5A and 5B are all at exposures which have fresh faces. The constant erosion by the river causes material to flake off and fall from these exposures with the result that there is no accumulation of weathered material on their faces. Also, the immediate surface was removed before the samples in question were taken from the exposures.

The difference between the specific gravity of bitumen near and back from weathered exposures is, no doubt, greater. Cross-section No. 16 (page 39) was made on an exposure which stands back from the shore of McKay river, and is not subject to rapid erosion at its base. As a result, the obvious effects of weathering have extended to a much greater depth on the surface of the exposure than is the case at cross-sections Nos. 1, 2 and 5 on Horse river. A series of samples was collected from strata 4C of cross-section No. 16 to gain some information about the effect of weathering. It will be seen from the analyses of these samples, recorded in Table 19, that the specific gravities of the bitumen in bituminous sand from the weathered surface crust, from just below the crust, and from the end of a 2½ foot bore hole, were 1.040, 1.025 and 1.010 respectively. The change in specific gravity appears to be marked and rapid going back from a weathered surface.

The specific gravity of fresh seepage bitumen is further evidence of softer, lighter bitumen back from exposures. The lowest specific gravity for bitumen in samples collected from cross-sections 22A, B and C (page 45) on the Athabaska river was 1.020. But fresh seepage bitumen from near these exposures had a specific gravity of 1.000.

The effect of proximity to the surface of exposures on the specific gravity of the bitumen has no bearing on the conclusion that the composition of the bituminous sand is independent of such proximity. Although there is a change in the quality of the bitumen, this change is too small to cause an appreciable accompanying difference in quantity.

It appears obvious that no detailed argument about the nature of the bitumen contained in the bituminous formation can be constructed upon the specific gravity determinations of bitumen from samples from exposures. These values can be taken, in general, to indicate the degree of hardening of bitumen that has taken place at the suface of an outcrop. As was explained in describing the method used in examining exposures, a trench was dug into the face of the exposures and a reasonable attempt made to get through the weathered material. It will be found that in most cases specific gravity results reported agree with the descriptions of the corresponding strata in indicating weathering and the presence of hardened beds of bituminous sand. The highest specific gravities —1.040 to 1.060—will be found to correspond in almost every case to top beds of bituminous sand. Such beds probably contain a decidedly hardened bitumen throughout. On the other hand, it is probable that the main mass of bitumen throughout the deposit does not exceed 1.025 in specific gravity.

While no detailed deductions from the specific gravity determinations are justifiable, one general deduction is rather obvious. There is a section of the bituminous sand formation which contains bitumen considerably lower in specific gravity than that found in the rest of the area. Examination of the analyses of samples from cross-sections Nos. 18, 19, 20, 21 and 25 on Ells river reveal this fact. It will be observed that there are examples of remarkably low specific gravity values for bitumen in samples from all the exposures examined on Ells river. Repeated values of 1.005 and 1.010 for specific gravity of bitumen from samples collected from Ells river exposures are in striking contrast to the values obtained with samples from all other sections of the area. There can be no other interpretation but that bitumen in the bituminous sands of the Ells river neighbourhood is distinctly lighter than the bitumen elsewhere.

The bituminous sand from Ells river exposures is exceptional in nature and stands in marked contrast with material from all other parts of the area. It looks different, and it feels different. It is more like an oily sand than one impregnated with a sticky bitumen. A closer study of this section would be of much interest and might lead to information of both practical and theoretical significance.

Variations in Distillates and Asphalt Residues from Bitumen.

The composition of the bitumen content of the bituminous sands, in terms of the familiar commercial products, is important. The connection between varying specific gravity and the composition of the bitumen is also interesting. A number of distillations of bitumen were made to gain some light on these matters.

The bitumens used for the distillation tests were obtained from a series of samples of several hundred pounds each. The points

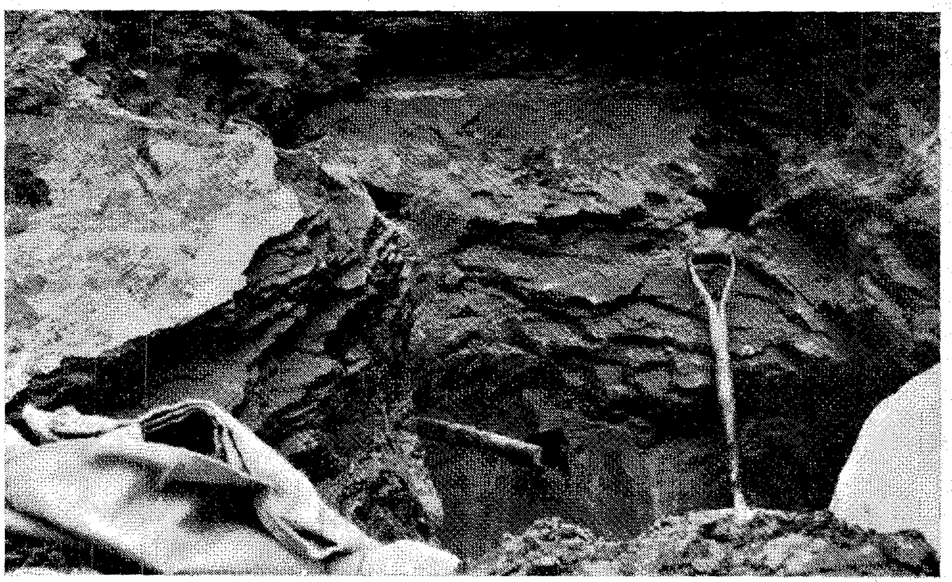

PLATE VII.—A Close View of a Hole Blasted into the Face of a Bituminous Sand Exposure.

where the samples were taken were chosen so as to be well distributed along a north-south section of the bituminous sand area, and to give samples containing bitumens varying over a considerable specific gravity range. Sizable holes were made in the cliffs by the use of blasting powder, pick and shovel, and the bituminous sand samples were taken about three feet back from the surfaces of the exposures.

The bitumens were distilled under a pressure of 40 mms. in a 500 cc. Hempel distillation flask with self-contained fractionating column. The method followed and equipment used was that of the U.S. Bureau of Mines, described in Bulletin 207. Specific gravities of distillates were determined by a Westphal balance. Viscosities were measured in a glass capillary viscosimeter, and equivalent viscosities in terms of Saybolt Universal units approximated by a calibration curve.

The bitumen in the bituminous sand sample was dissolved in benzene and the benzene solution placed in the distillation flask. Due to the action of the fractionating column of the distillation flask, and the low boiling point of the benzene as compared to that of the bitumen, a fairly satisfactory separation of bitumen and solvent was made. Charges of from 200 to 275 gms. of bitumen were secured for distillation by this means. Distillations were carried on under the 40 mms. of pressure, till cracking became noticeable. This effect took place at about 500°F. in all cases.

A summary of the results of distillations is given in Table No. 39. The division of the distillates into the various commercial fractions has been done in conformity with the practice of the U.S. Bureau of Mines. It will be noted that no distillate lighter than gas oil is recorded. The distillates from the tests were redistilled at atmospheric pressure, and it was found that most of the fraction recorded as gas oil had the volatility of kerosene. Some of it had the volatility of naptha, boiling below 200°C or 329°F. This was particularly true of the distillate from No. 19. However, the lowest

TABLE No. 39

SUMMARY OF RESULTS OF VACUUM DISTILLATIONS OF BITUMENS OF VARIOUS SPECIFIC GRAVITIES

Source of Sample Cross-Section No.	No. 19	No. 22A	No. 32	No. 11	No. 12	No. 30
Sp. Gr. of Bitumen Distilled 25°C/25°C	1.008	1.013	1.013	1.020	1.022	1.029
Distillation Products:						
Gas Oil	23%	15%	11%	8%	9%	7%
Nonviscous Lubricating Distillate	6%	5%	5%	5%	7%	5%
Medium Lubricating Distillate	5%	5%	9%	5%	11%	8%
Viscous Lubricating Distillate	....	6%	....	....	....	5%
Residuum	66%	69%	75%	82%	73%	75%
Properties of Residuum:						
Specific Gravity 25°C/25°C	1.035	1.040	1.038	1.040	1.046	1.053
Penetration, 25°C, 5 secs. 50 gms.	too	105	100	....	....	....
25°C, 5 secs. 100 gms.	soft	....	....	100	135	53

Definition of Distillation Products:

Gas Oil—Viscosity S. U. at 100°F, less than 50 seconds, specific gravity at 60°F greater than 0.825.

Nonviscous Lubricating Distillate—Viscosity between 50 and 100 seconds.

Medium Lubricating Distillate—Viscosity between 100 and 200 seconds.

Viscous Lubricating Distillate—Viscosity greater than 200 seconds.

specific gravities were all above 0.825. In fact the lowest specific gravity observed was 0.865. Consequently all distillates of viscosity less than 50 seconds have been classed as gas oil.

The results of the distillations show that the proportions of lower boiling constituents in the bitumens increase as their specific gravities decrease. But apparently this is not the only factor responsible for the range of variation in specific gravities. The residues from the distillations of the six bitumens examined display marked dissimilarities, although the distillations were all carried to approximately the same final temperature. Some of the bitumens appear to contain a larger proportion of hard asphalt than others. This difference introduces another factor influencing the significance of specific gravity variations of bitumens.

The distillation results for the bitumen from cross-section No. 19 bear out the observations already noted about the rather exceptional nature of the bitumen in the bituminous sand in the neighborhood of Ells river. This bitumen contains a relatively high proportion of the lower boiling constituents and a soft asphalt residue.

The distillation tests show that the bitumen content of the bituminous sands is not a definite product that can be described in a few words, or by one set of values of experimental tests. It is a substance which, throughout the bituminous sand formation, shows a very considerable range of variability.

Sulphur Content of the Bitumen.

The sulphur content of the bitumen in all samples examined is high. Practically every value reported is either 4% or 5%.

The heavy nature of the bitumen of the bituminous sands may be connected with its high sulphur content. The usual explanation given for this nature is that the light fractions of the original oil which entered the formation have been lost by evaporation and that what remains is the heavy residue. This does not seem a very plausible theory. The boring at Pelican river showed that the formation there, under a capping of 750 feet of shale and sandstone, contained the same sort of heavy bitumen observed in association with the sand at exposures. While evaporation of light fractions has no doubt taken place to some extent, especially in the area where the numerous outcrops are, the main reason for the heavy nature of the bitumen content of the bituminous sand is some factor other than evarporation.

A publication of the U.S. Bureau of mines[35] contains some comments which are significant in connection with the high sulphur content of the bituminous sand bitumen. Two quotations will be given, one from the introduction to and the other from the conclusion of the report. "Sulphur is apparently a normal constituent of crude petroleum, but in most cases is present in percentages of less than one-half of one per cent. Some crudes, however, contain more, and occurrences have been reported of heavy asphaltic oils with as much as five per cent. of sulphur." "Assuming that the

[35]The Distribution of Sulphur in Crude Petroleum. N. A. C. Smith and D. D. Stark. Bureau of Mines Report of Investigations No. 2582, 1924.

crude oil originally contains a very small amount of sulphur and comes in contact in the ground either with elementary sulphur or with some unstable sulphur compound at a temperature such that sulphur will react with the oil, it seems probable that a series of sulphur compounds might be formed. If the contamination with sulphur is sufficient in amount and the reaction takes place over a sufficiently long period of time, these sulphur compounds, which collectively might be called 'protoasphalt,' might be converted into true asphalts of high sulphur content. At a still later stage in the reaction oil-insoluble asphalts might be formed which would precipitate out of the oil; in fact, given sufficient sulphur and sufficient time and temperature, all of the oil might be converted into a solid asphaltic mass. Or it may be possible that Mexican crude as we know it is only a portion of the original crude, and that it is the liquid portion consisting of unaltered hydrocarbons, of sulphur derivatives and dissolved asphalt, which has migrated from its original source, leaving behind deposits of insoluble asphalt of extremely high sulphur content. These ideas are, of course, advanced merely as tentative, and it is fully recognized that a great deal of experimental work will be required before any final conclusion can be drawn."

Sulphur compounds are in evidence in the bituminous sand formation. Marcasite nodules were found embedded in the bituminous sand during the excavation of the shaft and were observed frequently in the loose rubble at the base of exposures. The water which filled the shaft was heavily charged with hydrogen sulphide. The oil which entered the bituminous sand formation probably had ample opportunity to come in contact with sulphur and its present inspissated condition may well be due much more to the sort of chemical reaction suggested in the report quoted than to evaporation losses.

The high sulphur content of the bitumen is likely the cause of the high specific gravities of its distillates. The Bureau of Mines found that there appeared to be a clear relationship between the specific gravities of Mexican crude oil and products from it and their sulphur contents, the specific gravities increasing with increasing content or sulphur. It was mentioned on page 67 that all the lower boiling fractions of the bitumens tested by distillation were classed as gas oil, even though much had the volatility of kerosene, because the specific gravities were in excess of 0.825. It was further mentioned that the lowest specific gravity determination made was 0.865. That was for a distillate boiling below 200°C. In some previous work, the sulphur in two gas oil distillates from bitumen was determined and found to be a little greater than two per cent. One was a vacuum distillate; the other, a steam distillate. The specific gravities were both approximately 0.91. In the case of the Mexican crude oil and products examined by the Bureau of Mines, a sulphur content of two per cent. corresponded to a specific gravity of about 0.85.

Outflows of Bituminous Sand.

Outflows of bituminous sand over the ground in front of exposures is an interesting feature. A quantity of bituminous sand seems to get into a mobile state and runs down the slopes like freshly mixed mortar would run. Later it hardens and what has happened can only be deduced from the way the material is found lying and the appearance of the hardened mass. Occurrences of this sort are common along the Athabaska river. Both Macoun and Bell mention this phenomenon in their geological reports and comment that the outflows of bituminous sand along the shore-line, although ordinarily hard, softened in the heat of the sun and caused a good deal of trouble to the boatmen who sank into them while tracking the canoes.

Two samples of this outflow bituminous sand were collected and examined. Results of analyses are recorded in Tables Nos. 12 and 13, pages 31 and 33. It will be noted that the bitumen contents are exceptionally high—16.8% in one case and 17.6% in the other.

The outflows are probably due to water. Bituminous sand containing 17% of bitumen must be very nearly saturated. A rough experiment indicated that the bitumen occupies a volume which is about 30% of the volume of the sand with which it is associated. If the bitumen took up a quarter of its weight of water[36], its volume would become about 35% of the volume of the associated sand. This volume of wet bitumen would be more than enough to fill the voids. Such supersaturated bituminous sand would be comparatively fluid, and if loosened by frost or other action might flow. Spread out in a comparatively thin layer, it would lose its water content in a short time and become fairly solid again.

Movement of bituminous sand under the influence of water was one of the difficulties encountered in the early days of bitumen mining in the Pechelbronn field in Alsace. These early workings were in material containing a much more viscous oil than that now being recovered from the oil mines. The invasion of these former workings by a mixture of sand, water and bitumen, is mentioned in the reports of Paul de Chambrier.[37]

The Shaft in Horse River Valley.

The shaft on Horse river was located on one of the flats that are characteristic of the first few miles of this valley. A total depth of forty-five feet was penetrated. An overburden of fifteen feet was found to be overlying the bituminous sand. This overburden consisted of bands of sand, sandy clay, bituminous sand rubble and boulders. The boulders occurred at the bottom of the overburden, immediately overlying the bituminous sand. The bituminous sand encountered was uniform in nature and rich in bitumen content. A number of marcasite nodules, varying in size from one to six inches in diameter, were found imbedded in the bituminous sand. A bore hole two and one-half feet deep at the bottom of the shaft reached a bed of clay at a depth of forty-five feet. Water, smelling strongly of hydrogen sulphide, came up through the bore hole from this clay. The clay probably represents the bottom of the bituminous formation at the location of the shaft.

[36]Fresh seepage bitumen contains one-quarter of its weight of water. cf. Tables Nos. 15 and 25 and the discussion on pages 59-63.
[37]L'Exploitation du petrole par drainage souterrain. Paul de Chambrier. Bulletin de L'Institut Du Petrole, May 31, 1923, p. 265.

The shaft was visited three months after it was sunk, and was found to contain a considerable depth of sulphur water. This was baled out. The shaft was again visited a year later and found to be filled up to the bottom of the overburden with sulphur water. This was pumped out. No bitumen had drained out of the bituminous sands into the shaft during the year and three months. If there were any commercial possibility of draining bitumen from the bituminous sands, comparable to the way oil drains into the oil mines at Pechelbronn, bitumen should have appeared during the time the shaft was being excavated. The absence of flow during the subsequent 15 months is less significant, as such flow would probably be inhibited by the water in the shaft.

Practical Methods of Excavating Bituminous Sand.

The operation of digging the shaft indicated some features about the fresh bituminous sand that have a bearing on the general problem of mining this material. Excavating the shaft by hand proved slow work, but certain ways of working made faster headway than others. The best way seemed to be to loosen up a hole in the centre of the bottom of the shaft by explosives, and then to slice off the sides of the hole with a shovel. This ready slicing off of thin layers is suggestive of the types of excavating machinery that might be used in working the bituminous sands. A steam shovel, for instance, would have this action.

Two of the principal firms manufacturing steam shovel machinery in America were consulted on the question of whether steam shovel equipment would be suitable for excavating the bituminous sands, and if so, the probable cost of operation. Their engineers were given the specific information for which they asked. Very definite final replies were received from both firms.

After careful examination of a fairly large sample of the bituminous sand tightly rammed into a stout box, of general information regarding the formation, and of detailed information regarding the specific occurrence represented by cross-section No. 32, both companies stated, without reservation, that their standard steam shovels would dig the bituminous sand from this or similar locations without difficulty. One company estimated that bituminous sand could be excavated from the deposit at cross-section No. 32 and loaded into cars for 10 cents per ton. The other company gave the total cost of operating, at this site, one of their steam shovels capable of digging 1,500 tons per 10 hour day, from which it could be deduced that the cost per ton of bituminous sand mined and loaded would fall below 10 cents, provided 1,000 tons or more were mined per day.

A steam shovel was operated in a bituminous sand deposit near Carpenteria, California. It handled the material without difficulty and at low cost. The small steam clamshell bucket used by the A. & G. W. Railway for unloading coal at its Edmonton shops has been used for unloading carload shipments of bituminous sand with entire satisfaction. Bituminous sand occurrences encountered during the construction of the right-of-way of the A. & G. W. Railway down the Clearwater river valley were handled by steam shovel.

CHAPTER V.

CONCLUSION.

Vertical Variations in the Bituminous Sand Formation.

The variations in the bituminous sand vertically throughout the thickness of the formation have been indicated fairly completely in the discussion of variations in bitumen contents. It is in order to review the main points, however, in connection with the practical considerations with which the remaining sections of the report will be concerned. The great thickness of beds making up the bituminous sand formation is one of its most imposing features. In the southern part of the area in the vicinity of McMurray bituminous sand exposures from one hundred and fifty to two hundred feet high are a common sight. But an ordinary observer is liable to be over-impressed with their size and fail to realize that they are not uniformily rich throughout their thickness.

A bituminous sand exposure of one hundred feet or more of well impregnated sand containing 9% or 10% or more of bitumen throughout practically its entire height is a rare occurrence. Eleven of the thirty-five cross-sections recorded in this report deal with one hundred or more feet of strata. Of these, two show three-quarters of the total thickness to be composed of bituminous sand of bitumen content greater than nine per cent.; four show about one-half the total thickness; and five, one-third or less of such material. These high exposures consist of a succession of beds of material varying quite widely, both in character of mineral matter and content of bitumen. The mineral matter may consist of sand comparatively free from silty or clayey material, of clayey or silty sand, or of clay. Where the mineral matter is sand with little silt present, a massive richly impregnated bituminous sand has generally resulted. Silty or clayey sand has been poorly impregnated with bitumen. Clay occurs mostly as thin partings interbedded with lean silty bituminous sand.

There is no system to the succession of rich and lean bituminous sand beds in sections through the sand formation. The formation is composed of a haphazard assortment of lenses of variable material. There is a general tendency, however, for upper beds to be very changeable in nature and composed mostly of lean material, and for the thick, massive, rich bituminous sand beds to occur toward the bottom of the formation.

From the standpoint of commercial development the high bituminous sand exposures are disappointing. Generally one-half or more of the thickness of beds is of poor grade material and most of the good material occurs toward the bottom. The upper beds practically constitute an overburden. Furthermore, the overburden of material lying on the bituminous sand formation, in most cases, increases rapidly in thickness back from the high exposures.

Lateral Variations in the Bituminous Sand Formation.

Because of the lenticular structure of the bituminous formation, lateral variations are pronounced. Within the extent of a sizable outcrop one can see beds pinching out. Exposures within a mile of each other give sections which bear little resemblance to each other except that both show variability. This characteristic of the formation has practical significance. It means that the composition of bituminous sand, as regards both bitumen content and nature of the mineral matter, excavated from commercial workings will be subject to considerable variation as the workings are extended in the course of development.

One broad feature of variability should be noted. It would appear that there are significant differences in the nature of the bitumen present in the bituminous sand in different parts of the area. The bitumen from the southern part is heavier than the rest. It contains a smaller proportion of the lower boiling point oily constituents, and yields a harder asphalt residue. The bitumen in the central and northern part of the formation is considerably lighter, containing more oil constituents and a softer asphalt residue. A zone of exceptionally light, soft bitumen occurs in the vicinity of Ells river. These differences in the general nature of the bitumen are likely to prove of considerable practical significance during the course of commercial development.

Favourable Locations for Commercial Development.

The discussion of the variations in the bituminous sand formation, as well as the general facts regarding its method of occurrence, indicate where favourable locations for commercial development are to be expected. Most of such locations will be found in the river valleys where erosion has reached but has not passed through the principal thicknesses of rich bituminous sand beds in the lower part of the formation. At these places, Nature has removed overlying deposits and the upper, changeable beds, and has left the choice bituminous sand under a comparatively thin covering of valley drift. River flats and benches occur throughout the bituminous sand area. The topographical maps prepared by S. C. Ells show their location. The nature of the bituminous sand which underlies them is sometimes revealed by exposures. In other cases, such information will be found only by prospecting with a drill or by sinking shafts. Suitably occurring bodies of bituminous sand near McMurray and along the Athabaska river below McMurray will be the most favourably located in regard to present transportation facilities.

Good locations for development work are not restricted, necessarily, to river flats and benches. Places such as that on Steepbank river at Cross-section No. 13 occur where high exposures show that most of the thickness of bituminous beds are of rich material, and that the formation is covered by an exceptionally thin overburden. Ells mentions areas along Beaver river[38] as being of a similar nature. Prospecting may reveal more locations of this sort and

[38]"Bituminous Sands of Northern Alberta," S. C. Ells, Mines Branch, Dept. of Mines, Ottawa, 1926, No. 632, p. 36.

extensions of transportation facilities may be undertaken which will give access to them.

Distinctly favourable conditions are sought, naturally, for initial steps in commercial development. While the proportion of the bituminous sand formation which offers such advantages is a small part of the whole, nevertheless the actual quantity of high grade bituminous sand which can be reached readily by present facilities of transportation or modest extensions of them, and which can be excavated under favourable conditions, is large. There is ample scope for an industry to grow extensively before the practical problems of working less favourably occurring material need be faced.

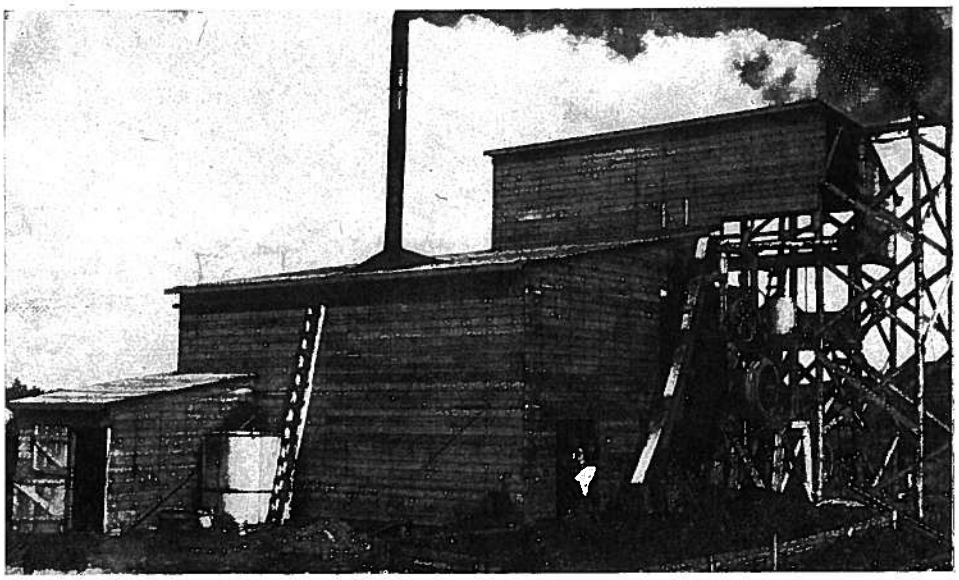

PLATE I.—Experimental Bituminous Sand Separation Plant,
Edmonton, Alta.

Report No. 18.

Scientific and Industrial Research Council of Alberta

The Bituminous Sands of Alberta

BY

K. A. CLARK and S. M. BLAIR

PART I.—OCCURRENCE.
PART II.—SEPARATION.
PART III.—UTILIZATION (In preparation)

PUBLISHED BY AUTHORITY OF THE HON. J. E. BROWNLEE,
Chairman of the Scientific & Industrial Research Council of Alberta.

EDMONTON:
PRINTED BY W. D. MacLEAN, ACTING KING'S PRINTER
1927

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The Bituminous Sands of Alberta

BY

K. A. CLARK and S. M. BLAIR

PART II.—SEPARATION.

Development of a Hot Water Separation Process.

ORGANIZATION

The Scientific and Industrial Research Council of Alberta, formed in January, 1921, carries on its work in co-operation with the University of Alberta.

The personnel of the Council at the present time is as follows:

HON. J. E. BROWNLEE, Premier of Alberta, Chairman.

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R. M. YOUNG, Canmore, Alberta.

EDGAR STANSFIELD, Honorary Secretary, University of Alberta.

Requests for information and reports should be addressed to the Honorary Secretary, Industrial Research Department, University of Alberta, Edmonton, Alberta.

LETTER OF TRANSMITTAL

HONOURABLE J. E. BROWNLEE,

Premier of Alberta,

Edmonton, Alberta.

Sir:

I have the honour to transmit herewith a report entitled "The Bituminous Sands of Alberta", Part II, prepared in co-operation with Mr. S. M. Blair.

The Scientific and Industrial Research Council instructed me to compile the results of our work to date on the bituminous sands for publication. Part I of the general report, dealing with the occurrence of the bituminous sand in Northern Alberta and our field examination of the deposit, has been published. The present report deals with our study of a method for separating the bitumen from the bituminous sand. Part III, which deals with the use of bituminous sand and of separated bitumen for road construction, is in preparation.

Respectfully submitted,

K. A. CLARK,

Research Engineer, Road Materials.

Department of Industrial Research,
University of Alberta,
Edmonton.

September 6th, 1927.

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by

K. A. Clark and S. M. Blair

PART II.

SEPARATION OF BITUMEN FROM ALBERTA BITUMINOUS SANDS

CHAPTER I.

INTRODUCTION.

The study and development of an economic method for separating the bitumen from the bituminous sands has been given a major place in the work of the Scientific and Industrial Research Council. The purpose of this report is to record the progress made.

Advantages of Separation.

The principal advantages of separation are:

1. The market available to bitumen is more extensive and varied than that available to bituminous sand.
2. The area of market which bitumen can enter successfully is much larger than that in which bituminous sands can compete, on account of the heavier freight charges for the latter.

There is one outstanding use for bituminous sand as such: pavement and other wearing surfaces can be made from it. The naturally occurring mixture of asphalt and sand can be modified by additions of mineral matter and by heat treatment to form a finished bituminous aggregate of excellent qualities. Examples of pavements made from bituminous sand and which have given long and satisfactory service can be pointed to in almost every section of America where this natural material occurs. Alberta is no exception. A stretch of asphalt pavement surface, compounded from Alberta bituminous sands was laid on a fairly heavy traffic street in the City of Edmonton during 1913[1]. No pavement surface in the city has given or is continuing to give better service than this one.

For free bitumen on the other hand, that is for the heavy asphaltic oil content of the bituminous sand separated from its sand association, there are several different and important uses apparent. The bitumen can be used for pavement and other wearing surface

[1]Bituminous Sands of Northern Alberta, by S. C. Ells, Mines Branch, Ottawa, No. 632, pp. 75-81.

construction as readily, if not more readily, than the natural bituminous sand. It is free bitumen that pavement engineers are accustomed to use and have equipment for handling. In addition, there are types of road construction other than pavements, involving the use of asphalt and asphaltic oils, for which separated bitument is admirably suited. Important among these, from the standpoint of Western Canada, is the bituminous surface treated gravel road. The normal development in highway improvements in the prairie provinces is bound to bring this type of moderate priced road surface into extensive use. A liquid asphalt which can be placed in a tank, hauled to the road and sprayed onto its surface is needed for this work. Separated bitumen answers this requirement; bituminous sand does not.

Asphalt emulsions are coming rapidly into prominence, especially for road work. It is a handy form in which to use the asphalt for maintenance of bituminous and concrete pavements and even new construction is being done by use of emulsions[2]. Their use will probably extend to bituminized gravel construction. Quite apart from road work, asphalt emulsions are proving useful as a means of applying a waterproofing coat to concrete structures. A substantial demand for asphalt emulsions is likely to develop in Western Canada, as it is developing elsewhere, and separated bitumen from the bituminous sands, in emulsified form, could share this market.

Coal is briquetted in Alberta, and some hundreds of tons of asphalt binder were used by the most recent briquetting plant during the first year of its activity[3]. This use for asphalt has possibilities of large development.

The bitumen content of the bituminous sands is a semi-liquid asphalt. It is too soft, in its natural state, for some of the uses to which asphalts are put. However, once separated from the sand, its physical characteristics can be modified, by regular commercial processes, to meet the range of asphalt specifications.

It is now practical to regard the bitumen content of the bituminous sands as a crude oil and therefore a potential motor fuel. The "cracking" process has been developed to the stage where oil as heavy as this can be handled successfully and turned into high yields of gasoline. Once separated from the sand, the bitumen could be used as charging stock by cracking plants now in commercial operation[4]. General conditions in the oil industry are not yet propitious for the development of the Alberta bituminous sands for manufacture of gasoline. But the recent improvements of the cracking process have opened up an almost unlimited outlet for separated bitumen which will be taken advantage of when the demand for crude oil becomes more keen and its price commences to rise.

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[2]Indiana State Highway Commission Specifications for Bituminous Materials, 1925. Emulsified Asphalt for Crack Filler and Cold Mix Repairs; for Cold Mix Resurfacing Work.

[3]The present annual consumption of asphalt binder at the briquetting plant of the Canmore Coal Co., Canmore, Alta., is approximately one thousand tons. Under capacity production with present equipment, the consumption would be five or six thousand tons.

[4]cf. account of cracking tests performed by the Universal Oil Products Co. on bitumen separated from the bituminous sand, pp. 32-34 of this report.

An industry based on excavating and marketing bituminous sand would be dependent on a raw material having but one use. If, on the other hand, it separated the bitumen from the bituminous sands, it would have a product that could be adapted readily for sale for all the purposes to which asphalts are put. Separated bitumen would be as suitable as bituminous sand for the one main use of the latter, as well as being suitable for other purposes for which the latter is not. It would meet the present needs of Western Canada for bituminous materials better than would bituminous sand; varied outlets for it will come into prominence as Western Canada develops; and eventually it will take a large share in supplying the country's demand for crude oil and its products.

In addition to the matter of possible markets for bituminous sand and separated bitumen, there is the matter of the marketing area which the two materials can cover. The controlling factor in this consideration is freight rates, and it is apparent at once that the limiting action of transportation costs will be much more restrictive on bituminous sand than on bitumen. At any given marketing point, the price at which bituminous sand can be sold is defined, practically, by the cost of equivalent amounts of refinery asphalt and local sand. At the time of writing, asphalt for pavement work can be delivered to the paving plant of the City of Edmonton for $35.00 per ton, and local sheet asphalt sand for $1.75 per yard. On the basis of these figures, a ton of bituminous sand[5] at Edmonton contains material worth not more than $5.50. Its value over a considerable area would be approximately the same. If, under stress of competition, the cost of refinery asphalt were reduced to $25.00 per ton[6], the limiting value of a ton of bituminous sand would become $4.25. To date, the freight charges on a ton of bituminous sand in carload lots from the deposits to Edmonton has been $4.00. And Edmonton is the point closest to the deposits on the fringe of the marketing area. No doubt more favourable freight rates than this could be secured if the excavating and use of bituminous sand were on a large scale. But even so, it is obvious that they will be a serious obstacle limiting the marketing range to a comparatively small area of the populated part of the province.

Freight rates will also limit the marketing area for separated bitumen. But the distance to which bitumen could be transported before production costs[7], plus shipping charges equalled the price of competitive materials would be much greater than for bituminous sand. Consequently its chances of reaching a market of sufficient magnitude to support a large scale industry are much better than those of the latter.

The direct use of bituminous sand for pavement construction provides the simplest means for starting a bituminous sand in-

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[5]It is assumed that the bituminous sand would have an original bitumen content of 15% by weight which would be reduced to 13% by loss of volatile constituents during the heating and mixing operation of making it up into pavement aggregate. This is a liberal assumption. Bituminous sand containing 15% bitumen is rich material. And laboratory vacuum distillation tests on the bitumen show that at least 25% of it must be distilled off before a residue with a penetration comparable to pavement asphalt is obtained.

[6]A price of from $25.00 to $28.00 per ton for pavement asphalt in tank car lots at Edmonton was quoted in 1924.

[7]cf. pp. 34 and 35 for estimate of cost of production of separated bitumen.

dustry. The first steps in this direction have been taken already. The McMurray Asphaltum and Oil Company has been making commercial shipments of bituminous sand from its lease at Draper during the past several years. The starting of other enterprises of similar kind is rumored. As more money is invested in these undertakings, the urge will be felt to expand the industry and to take advantage of the much wider scope of usefulness open to separated bitumen. A practical method of separation, adapted to the Alberta bituminous sands, will then be required. The separation studies of the Scientific and Industrial Research Council were undertaken in anticipation of this need. These studies have progressed so successfully that it can be said that little difficulty remains other than the development of details incidental to commercial production. The working out of these details must be left to private enterprise, as such work is outside the scope of government investigations.

THE HOT WATER METHOD OF SEPARATION.

The general method of separation by hot water was found best for detailed study and adaptation to Alberta bituminous sands. This is an old method which has been used in a crude way at various times in various countries, and which is now being revived and improved. For instance, it was used in the early days of the Pechelbronn oil field in Alsace. The first workings there date back to 1735 when a tunnel was driven into a hillside and encountered oil sands. These were excavated and the thickened oil was washed out by hot water. As the mines extended farther into the formation, lighter oil was reached, and finally it commenced to seep out into the galleries. This method of getting the oil then superseded the washing process. Oil wells superseded the collecting of the seepage oil when a well, sunk for prospecting purposes in connection with the mining, unexpectedly struck flowing oil. By the time of the late war, these wells had ceased to be productive and, under stress of war conditions, a mine was opened up in the main part of the field. It was planned to excavate the sand and wash out the oil remaining in it with water. But since large quantities of oil seeped into the galleries of the mine, the washing operation has been postponed for the present. At Wietze, Germany, where oil mining has been undertaken as a result of the success at Pechelbronn, oil is recovered by washing the excavated oil sand as well as by drainage into the galleries[8].

On the American continent, the hot water method of separation has been applied, most particularly, to the Californian bituminous sands. During the period between 1899 and 1913 a number of plants were erected and operated. As far as can be judged from available accounts of these undertakings the scheme in its simplest form was used. The bituminous sand was placed in hot water and agitated. Although there was considerable complication of equipment, there was no attempt to gain an understanding of the factors behind the action of hot water on the bituminous sands and

8Oil Mining. Edward Bloesch. Bul. Amer. Ass'n Petro. Geologists, April, 1926, p. 405.

to arrange conditions in the light of them. The results appear to have been unsatisfactory and the undertakings were abandoned. Incentive to follow the matter further was removed by the phenomenal rise of the petroleum industry in California.

Interest in America regarding the hot water method has revived somewhat during the past few years and modified processes are being proposed. The modifications are following along the line of pretreatment of the bituminous sand with aqueous solutions and of better devised procedures for washing the pretreated material with hot water. Possibilities of development of Alberta bituminous sands appear to be one of the main reasons for renewed interest in the hot water process[9].

Of interest in connection with, though not bearing directly on, the hot water separation of bituminous sands, are the proposed methods of recovering oil from exhausted oil fields by flooding with water and alkaline aqueous solutions[10]. These schemes, as well as the washing procedure being used in Germany, are concerned with sand containing oil much lighter and more fluid than the bitumen in bituminous sands such as those of Northern Alberta. The general principles involved are probably much the same in all cases, but the practical difficulties are greater with the bituminous sands.

Besides the hot water method, there are two other general methods that can and have been used for recovering oil from bituminous sands. The bitumen content can be dissolved away from the sand by organic solvents and the solvent reclaimed by distillation. Prevention of serious loss of solvent without resorting to costly complication of equipment and procedure is the main drawback to this scheme. Or, the bituminous sand can be destructively distilled in a retort and the oil vapors condensed and collected. The necessity of heating and handling large quantities of sand in the retort in proportion to the bitumen present constitutes a serious difficulty. In addition, the efficiency of the thermal decomposition of the bitumen by simple retorting is so far below that of the modern cracking processes that, in the case of bituminous sands, the logical procedure is clearly to separate the bitumen and put it through properly designed cracking equipment, if its breaking down into lighter hydrocarbons is desired[11].

STUDIES OF THE HOT WATER SEPARATION PROCESS.

The practical objective of a bituminous sand separation process is the removal of the bitumen from the sand as completely as possible. The mere breaking down of the adhesion between bitumen

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[9]cf. Bituminous Sands of Northern Alberta, by S. C. Ells, Mines Branch, Ottawa, No. 632, 1926, pp. 173-236, for review of processes that have been tried or are being proposed for separating oil from bituminous sands.

[10]The Effect of Flooding Oil Sands with Alkaline Solutions. R. C. Beckstrom and F. M. Van Tuyl. Bul. Amer. Ass'n Petro. Geologists, March, 1927, p. 223.

[11]The Bowie-Gavin Process: Its Application to the Cracking of Tars and Heavy Oils, Also to the Recovery of Oil from Oil-Soaked Sands or Shales or from Oil Shales. C. P. Bowie, Bureau of Mines, Wash., Technical Paper No. 370, 1926. A study of this paper shows that yields of gasoline from the oil in the oil sands processed by the Bowie-Gavin retort compare unfavourably with results of cracking of similar oil in modern cracking plants. Since the purpose of thermal decomposition is mainly production of motor fuel, the retorting of materials such as bituminous sands from which bitumen can be separated from its purely mechanical association with mineral matter does not appear a logical procedure.

and sand is not sufficient. If bituminous sand and soap solution, for instance, are shaken together in a glass container, the bitumen films surrounding the sand grains are displaced from the sand surfaces and when the mixture settles clean sand can be seen through the glass. But the sand and bitumen are still mixed together in the bottom of the vessel, though in a modified relationship from that which existed in the original bituminous sand. If the soap solution is poured off, the bitumen coheres and enmeshes most of the sand. M. E. Fyleman has been granted a patent on this action[12]. In his patent specification, he says: "In practise, the operation may be carried out with tar sand by heating it, with stirring, with water in which one of the above-mentioned reagents such as an alkali soap or an alkali carbonate, hydroxide or silicate has been dissolved, only very small proportions of any of these compounds being necessary. On heating to from 60° to 80°C., the tar is thus stripped from the sand and may then be separated from the latter by levigation or by other suitable means." All this is quite true, but nevertheless it does not constitute a practical method of separation. The real problem of removal of bitumen from the sand is passed over by saying that it can be accomplished by levigation or by other suitable means. The best that such a procedure will accomplish is to eliminate some mineral matter, leaving a sandy bitumen much too impure to be worth the cost of producing it.

Many experiments were tried in the laboratories of the Research Council before a separation process was found which had practical possibilities. Finally it was noted that when bituminous sand which had been kept in contact for some time with a hot dilute solution of silicate of soda was introduced with agitation into a comparatively large body of hot water, a complete dispersion of the bituminous sand took place, and that when the agitation was stopped clean sand settled to the bottom and bitumen collected on the surface in the form of a light froth. In the original experiments, the bituminous sand with about twenty-five per cent. of its weight of one per cent. silicate of soda solution was placed in a pan and left for several hours in an oven at a temperature slightly below 100°C. The solution penetrated the bituminous sand and was completely taken up by it, changing its nature from a sticky, coherent mass to a granular one. A quantity of this treated material was placed in a basin of hot water and immediately stirred. The small mass dispersed in the water and a layer of frothed bitumen rose to the surface. Repeating the operation, a considerable amount of treated bituminous sand could be separated in the same supply of hot water, the cleaned sand accumulating at the bottom and the bitumen piling up on the surface in a thickened froth layer. The separation was surprisingly effective, even when done in this crude way. The sand which settled after agitation ceased had a clean, bitumen-free appearance, and the separated bitumen contained only about ten per cent. of mineral matter and twenty to twenty-five per cent. of water.

Indications from many observations during the course of these studies lead to the view that the separation of the bitumen by the

[12] A Process for Separating Mineral Oils or the like from Sand or Rock. M. E. Fyleman. Eng. Pat. 163,519, 1920; Can. Pat. 203,676, 1920; U.S. Pat. 1,615,121, Jan. 18, 1927.

general procedure just outlined is due to the formation of bitumen emulsions and the behaviour of these emulsions under the conditions prevailing. It would appear that the pre-treatment of the bituminous sand with silicate of soda solution results in the formation of a water-in-oil emulsion of the bitumen. When this water-in-oil emulsion is introduced into an excess of water it inverts to an oil-in-water emulsion which is unstable and breaks. Minute globules of bitumen form and rise to the surface of the water. This action can be seen at the commencement of a separation run in the equipment now used. Care must be exercised to conduct the pre-treatment of the bituminous sand in such a way that no premature separation of bitumen takes place. If this happens, poor final separation will result. The inverting of the emulsion should take place under conditions which make it possible for the bitumen and sand to get away from each other as completely as possible.

A study of the formation of the two types of bitumen emulsions and their behaviour under varying conditions is being made. It is expected that this work will supplement, in a practical way, the present understanding of the separation action and lead to improved procedure.

CHAPTER II.

EXPERIMENTAL WORK.

SEPARATION PLANT OPERATIONS IN 1923.

The separation process developed by laboratory experiments appeared practical for large scale operations. Consequently it was decided to try it out in fair-sized equipment. Two carloads of bituminous sand were bought from the McMurray Asphaltum and Oil Company during the fall of 1922 and placed in a stock pile at the University of Alberta. A plant was designed having a capacity for treatment of a batch of two and a half to three tons of bituminous sand and then to separate it continuously at the rate of half a ton per hour. This plant was built and operated during the spring and early summer of 1923. The undertaking was carried through successfully, and about eighty-five tons of bituminous sand were put through the plant without serious difficulty.

A site for the separation plant which met the situation fairly well was found in the basement of the University power plant building. There was plenty of floor space, and steam and electric power connections were at hand. There were several drawbacks, however, which set limitations on the design of the plant and caused inconvenience in operation. The height of the basement room was not enough to allow of a plant design which provided a fall from one end of the plant to the other. This feature was responsible for the main difficulties in the operation of the plant. It was also a bad arrangement to have to throw tons of bituminous sand into a basement and then lift it all out again after separation. These difficulties were not serious enough, however, to materially interfere with the attainment of the purpose of the work.

Description of Plant.

The main features of the separation plant design are shown in Fig. 1. At the head of the plant a treatment box was provided in which the bituminous sand to be separated received a preparatory treatment with silicate of soda solution. This box, like all the other boxes of the plant, was made of No. 16 gauge sheet metal. It was 10½ feet long, 2½ feet wide and 4½ feet deep. The general shape of the box can be seen from the drawing. A horizontal screw conveyor was fitted into the V-shaped bottom of the box, and an inclined screw conveyor, surrounded by a tube, was placed in the V of the constricted end. The box would hold three tons of bituminous sand. The expedient of feeding the bituminous sand uphill out of the treatment box to the rest of the plant by means of a screw conveyor on a 45° incline was one that no one wished to endorse. But because of lack of head-room the treatment box could not be raised. Preliminary experiments were run to determine whether a screw conveyor working in a tube would bring up treated bituminous sand. Indications were favourable, so the screw conveyor feed was adopted, and it worked reasonably well.

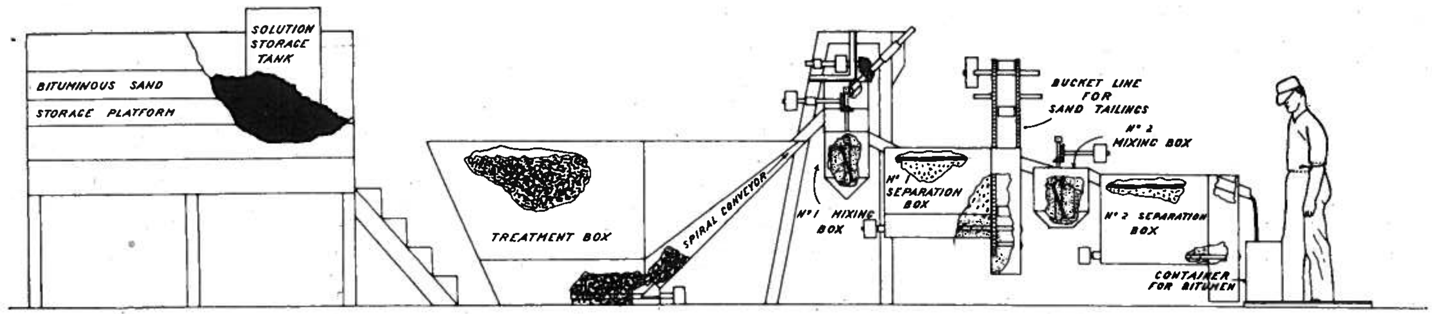

Fig. 1.—Bituminous Sand Separation Plant, 1923.

The inclined screw conveyor delivered treated bituminous sand to No. 1 mixing box. This was a sheet metal vessel, 15 inches square and about 20 inches deep. A paddle was provided for agitating the water maintained in the box. An overflow pipe connected No. 1 mixing box with No. 1 separation box.

No. 1 separation box was rectangular in construction, 36 inches long, 15 inches wide, and 37½ inches deep. The bottom was V-shaped, and had a screw conveyor fitted into it. At the end of the box, and built as part of it, there was a boot or sand sump, forming a 10-inch addition to the length of the separation box and extending 10 inches deeper. A bucket line was fitted into this boot. Sand tailings sinking through the water contained in the separation box were carred into the boot by the screw conveyor and then picked up by the bucket line.

A No. 2 mixing box and a No. 2 separation box were provided in the plant, and differed very little in design from those already described. No. 2 mixing box had a partition or baffle separating the overflow pipe from the part of the box where the paddle revolved. The purpose of this baffle was to make all the material entering No. 2 mixing box from No. 1 separation box pass downward and under the baffle before it could proceed further. It was intended that the second mixing box should remove more sand from the bitumen concentrate floating off from the first separation box, and it was feared that this bitumen might pass over the surface of the second mixing box without getting properly broken up and agitated. No bucket line was provided for No. 2 separation box. The little sand that accumulated in the boot was removed with a hoe.

The water and steam piping for the plant is not shown in the diagram, but is easily described. Each box was provided with a system of closed steam coils. The condensate in the heating coils ran into a trap, which discharged it into a tank where it was measured. A steam pressure of about 15 pounds was used. A pipe for introducing water into the plant was connected to Nos. 1 and 2 mixing boxes. These connections were used to give the mixing and separation boxes an initial filling with water, and to replace the continuous loss of water from the system during operation. A water-circulating system from each separation box into its corresponding mixing box was provided by leading a pipe from the lower part of the separation box through a motor-driven centrifugal pump and up into the top of the mixing box. A connection from the discharge side of the pump for No. 2 separation box was brought forward to No. 1 mixing box so that a portion or all of its discharge could be introduced into No. 1 mixing box.

The plant was driven by electrical power, through a shaft suspended above the plant from the ceiling, and a countershaft on the floor. All screw conveyors were turned at a speed of 40 revolutions per minute; the mixing box paddles were run at 100 revolutions per minute; while the bucket line travelled 20 feet per minute. These speeds gave the plant a throughput of one-half ton of bituminous sand per hour.

A strong framework supported the various boxes and carried the bearings, etc. All boxes were surrounded with lumber for support and to act as insulation against the loss of heat. A wooden charging platform was provided at the head of the plant.

Bituminous sand was brought from the stock pile in wheelbarrows, weighed, and thrown through a window opening onto the charging platform above the treatment box. A batch of approximately three tons was brought to the plant, and placed in readiness for treatment. A quantity of silicate of soda solution was poured into the empty box. The quantity of solution used was so controlled that it thoroughly soaked the charge, but did not provide any excess. Solutions used varied in strength from ½% to 2% by weight of liquid silicate of soda. The weighed quantity of bituminous sand was thrown into the solution. The treatment box was charged at the close of the day, so that the material would be ready for a run next morning. Steam was turned into the steam coils of the treatment box, and the charge left to heat up to about 80°C. to 90°C. Various times of heating were tried. The silicate of soda solution thus penetrated through every portion of the bituminous sand, and reduced it to a uniformly mushy, granular mass.

The separation of the bitumen from the treated bituminous sand was a continuous operation. The various boxes were filled with water, and the pumps started. The level of the water in the separation boxes were brought to a point a few inches below the overflow pipes, and held there. The steam was turned into the heating coils, and the temperature of the water in the plant brought up to about 85°C. Power was then applied to the moving parts and the separation process commenced. The screw conveyors in the treatment box lifted treated bituminous sand up to No. 1 mixing box, and dropped it onto a short platform sloping into the water. The stream of water from the pump, entering the top of No. 1 mixing box, washed the bituminous sand into the body of water agitated by the paddle. The treated bituminous sand, on being introduced into the agitated water, dispersed immediately into clean sand grains and finely divided bitumen. Water, with sand and bitumen suspended in it, continually overflowed into No. 1 separation box. This box contained a large body of comparatively quiet water, and the sand particles there sank to the bottom, while the bitumen floated on the surface in a frothy layer. The sand from the bottom was carried into the sand sump by the screw conveyor, and was picked up by the bucket line. The bitumen layer accumulated on the surface until it overflowed through the outlet pipe into No. 2 mixing box. The main separation action took place in No. 1 mixing box. The action sought in No. 2 mixing box was to further reduce the mineral content of the bitumen concentrate. The action in No. 2 separation box was the same as that of No. 1. Bitumen finally flowed through the outlet at the end of the plant, and was collected in suitable vessels.

Several features about the bucket line and the elimination of the sand tailings should be mentioned. The buckets, filled with very fine, wet, sand tailings, refused to discharge. This difficulty was overcome by directing a jet of hot water into the buckets as they travelled along the horizontal portion of the bucket line over the box in which the sand tailings were collected. This jet was connected to the discharge side of the two centrifugal pumps. The sand tailings box had a false end filled with coarse gravel, which formed a filter column covering the outlet in the bottom of the box. The wet tailings and the water jet introduced a considerable quantity of water into the tailings box, and this excess water drained away through the gravel into the outlet pipe leading to the sewer. Although the tailings in the buckets appeared clean, they yielded further bitumen when dropped into the water in the tailings box, so that a considerable amount of bitumen accumulated as a layer on the water. This bitumen was skimmed off from time to time and put back into the treatment box.

The constant loss of water from the plant was balanced by the introduction of fresh water. No automatic control was provided to keep the water levels constant, but the flow was watched and regulated from time to time to maintain the level. The principal losses were due to the water carried in the sand tailings and to the water jet emptying the buckets.

Data.

Details of nine consecutive runs are given in Table I. The conditions were deliberately varied over a wide range in the series. The strength of silicate of soda solution was varied from 0.8% to 2.0%. The length of time of treating the bituminous sand with the hot silicate of soda solution was varied from 1 hour to 7¼ hours. The quantity of dirty water eliminated from the plant by the introduction of fresh water was varied from 2,200 pounds to 10,750 pounds per run. These variations caused a marked difference in the effectiveness of the separation as can be noted from the figures in the table. Sand tailings were obtained which retained from 6½% to 2% bitumen. The bitumen concentrates, free of water, contained from 12% to 8% of mineral matter. It should be understood in connection with these figures, that no attempt was made to put each run through under optimum conditions; on the contrary, as much variation as reasonable was made in order to gain knowledge of the effect of the different factors.

The heat consumption for each separation run and the data from which it was calculated are recorded in Table I. The heat used for treatment is the sum of the heat content of the silicate of soda solution placed in the treatment box along with the bituminous sand and the heat given up by the steam condensed during the heating period. The silicate of soda solution was raised from 15°C. (59°F.) to 50°C. (122°F.). Steam at 109°C. (228°F.) was condensed to water at 95°C. (203°F.). The heat used for separation is the sum of the heat content of the hot water introduced into the separation boxes and the heat given up by the steam condensed during the separation operation. The heat content of the water is taken as the heat necessary to raise it from 15°C. (59°F.) to the recorded average temperature at which it was put into the plant.

An estimate of the cost of heat can be calculated for the runs recorded in the table. The smallest total of treatment and separation heat was 329,000 B.T.U. per ton of bituminous sand separated; the largest total was 766,000 B.T.U. The University Power Plant generates 1,000 pounds of steam, at 150 pounds pressure, for a total cost (including fuel, labour and overhead) of 45 cents. Using this price for steam as a basis for calculating heat values, the minimum cost indicated by the runs recorded in Table I for treatment and separation is 12½ cents per ton of bituminous sand, and the maximum cost 29½ cents. The average cost for treatment is 4 cents, and for separation 15 cents.

Some approximation of the power costs can also be made. The average length of time for putting through runs of 2½ tons was 6½ hours. It required 2¾ h.p. to run the machinery idle, and 5¾ h.p. loaded. On the same basis it would require 15 h.p. hours per ton of bituminous sand. Taking the steam requirement per h.p. hour at the high value of 35 pounds, and the cost of steam at 45 cents per 1,000 pounds, the cost for power is 23½ cents per ton for separating the bituminous sand.

The costs for heat and power for separating a ton of bituminous sand should not be added together in reckoning the total cost. If the power were generated by a steam engine, all the exhaust steam from the engine could be used in the heating coils of the plant and for heating water. The maximum requirement of 35 pounds of steam at 150 pounds pressure, per h.p. hour, has been allowed in estimating the quantity and cost of steam for power. This quantity of steam would produce the power required and turn steam into the exhaust at the 228°F. temperature used for passing through the heating coils of the plant. Fifteen h.p. hours would provide 525 pounds of exhaust steam per ton of bituminous sand treated. The average heat consumption for the nine runs, per ton of bituminous sand, was 487,000 B.T.U. For these runs, the quantity of steam at a temperature of 228°F. required for the heating is about 435 pounds. This quantity is less than the available exhaust steam. Thus the cost of the power required also covers the cost of the required heat.

It should be emphasized that all estimates of the cost for heat and power for separating the bituminous sand are based on the data obtained during the runs, as actually carried through and recorded in Table I. No account is taken of obvious savings in both heat and power that could be made in a better designed plant and regular operation.

The average weight of silicate of soda used per ton of bituminous sand treated was 3¼ pounds. Silicate of soda costs 1¼ cents per pound f.o.b. Edmonton. The cost per ton of sand is therefore about 4 cents.

The separated bitumen produced by this first plant was used experimentally for stabilizing earth roads. This experiment has given encouraging results[13].

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[13]Fourth Annual Report, Scientific & Industrial Research Council of Alberta, 1923, p. 68.

TABLE I.—RESULTS OF NINE CONSECUTIVE RUNS OF SEPARATION PLANT.

Date of run............June, 1923	1	4	5	6	7	8	11	13	14
Weight of Bituminous Sand charge ....lbs.	5,300	5,650	5,500	5,200	5,100	5,050	4,700	5,650	5,500
TREATMENT:									
Duration ....hrs.	7¼	1	2	2¼	2¼	2	2½	3	4½
Steam Condensed ....lbs.	415	167	182	106	227	250	258	273	202
SEPARATION:									
Duration ....hrs.	7	6	5¾	5¾	6½	7¾	6½	6¼	6
Steam Condensed ....lbs.	545	715	536	522	600	637	387	1,183	967
Water Introduced ....lbs.	2,900	2,700	2,700	2,200	2,200	4,400	3,500	10,750	10,000
Temp. Water Introduced....°F.	158	160	167	156	158	163	158	126	122
Silicate of Soda Soln.:									
Wt. per ton of Bituminous Sand ....lbs.	180	240	185	190	200	200	235	195	235
Concentration ....%	1.7	0.8	0.8	1.2	1.7	2.0	1.8	2.0	2.0
Heat Consumption per ton of Bituminous Sand:									
Treatment, 1000's of B.T.U.	163.5	72.4	76	51.5	99	109	121	106	86
Separation, 1000's of B.T.U.	308	342	295	277	315	427	308	660	570
Total	471.5	414.4	371	328.5	414	536	429	766	656

Date of Run............June, 1923	1	4	5	6	7	8	11	13	14
ANALYSES:									
Bituminous Sand:									
Bitumen ....%	17	....	15	13	14.5	13	12	13.5	14
Sand ....%	83	....	81	82	80.5	80	82	83	82
Water ....%	0	....	4	5	5	7	6	3.5	4
Concentrate from No. 1 Separation Box:									
Bitumen ....%	70.5	....	68.5	65.5	60	63.5	49	62.3	56
Sand ....%	7.5	....	8.5	8.5	9	8.5	11	7.7	9
Water ....%	22	....	23	26	31	28	40	30	35
Concentrate from No. 2 Separation Box:									
Bitumen ....%	66	70	64.5	72.5	61.5	65	55	59	63
Sand ....%	7	8	8.5	7.5	5.5	7	7	7	9
Water ....%	27	22	27	20	33	28	38	34	28
Dry Sand Tailings:									
Bitumen ....%	3.6	6.5	4.5	3.8	....	2.8	2.0	2.0	2.0

REMARKS: "S" Brand silicate of soda used (Philadelphia Quartz Co.); $Na_2O:SiO_2=1:3.86$; 6.4% Na_2O; 34°Be. Steam supplied to plant at temperature of 228°F. and condensed to water at 203°F. Silicate of soda solution was at 122°F. when placed in treatment box. All percentages are by weight.

SEPARATION PLANT OPERATIONS IN 1924.

The successful outcome of the 1923 project confirmed the belief that this process was a practical one and suited to large scale work. Consequently it was decided to build a larger separation plant designed for continuous treatment, as well as continuous separation, and to separate about five hundred tons of bituminous sand to obtain bitumen for further road experimentation.

The erection of the plant in the bituminous sand area had been considered, but it was decided against for this stage of experimental work. Location at Edmonton gave the advantage of handiness to supply houses and machine shop facilities. Through the courtesy and co-operation of the Provincial Department of Railways, a site for the new plant was secured at the Dunvegan Yards on the outskirts of the City of Edmonton. The Dunvegan Yards is the southern terminus of the railway tapping the bituminous sand area, and carload shipments of the sand could be spotted alongside the plant site.

Description of Plant.

The new plant was designed during the winter of 1923-24 and erected the following spring. The general plan of construction was much the same as that for the first plant. The principal modification consisted of a treatment box of several compartments so that treatment of bituminous sand could be carried out simultaneously with the separation operation and so that a supply of treated material could always be available for separation. Also, the treatment box was placed over the separation boxes so that a gravity feed could be used in place of the inclined screw conveyor lift of the first plant. Another change was that the sand tailings from the first separation box, instead of the separated bitumen, were put through the second box. The previous year's experience had shown that rerunning the separated bitumen accomplished little, but that rewashing the sand tailings separated considerable bitumen.

A diagrammatic drawing of the plant is shown in Fig. 2. Each of the four compartments of the treatment box was of two tons capacity and was provided with a water-tight door, inclined floor, and steam coils. The whole box was mounted on wheels on a track so that any compartment could be brought into position for discharge into the plant. Bituminous sand was heated in these compartments in contact with silicate of soda solution for some hours in preparation for separation.

The treated bituminous sand was discharged into a hopper of two tons capacity set over a screw conveyor which delivered into No. 1 mixing box.

The mixing boxes were of 3-16 inch metal, 19½ inches square by 27½ inches deep, with an overflow leading into the corresponding separation boxes. They were provided with paddle agitation.

The separation boxes were of 3-16 inch metal, 2 feet wide, 5 feet long and 5 feet deep. They were fitted with steam coils and had a V-shaped bottom with a spiral conveyor leading to a sand

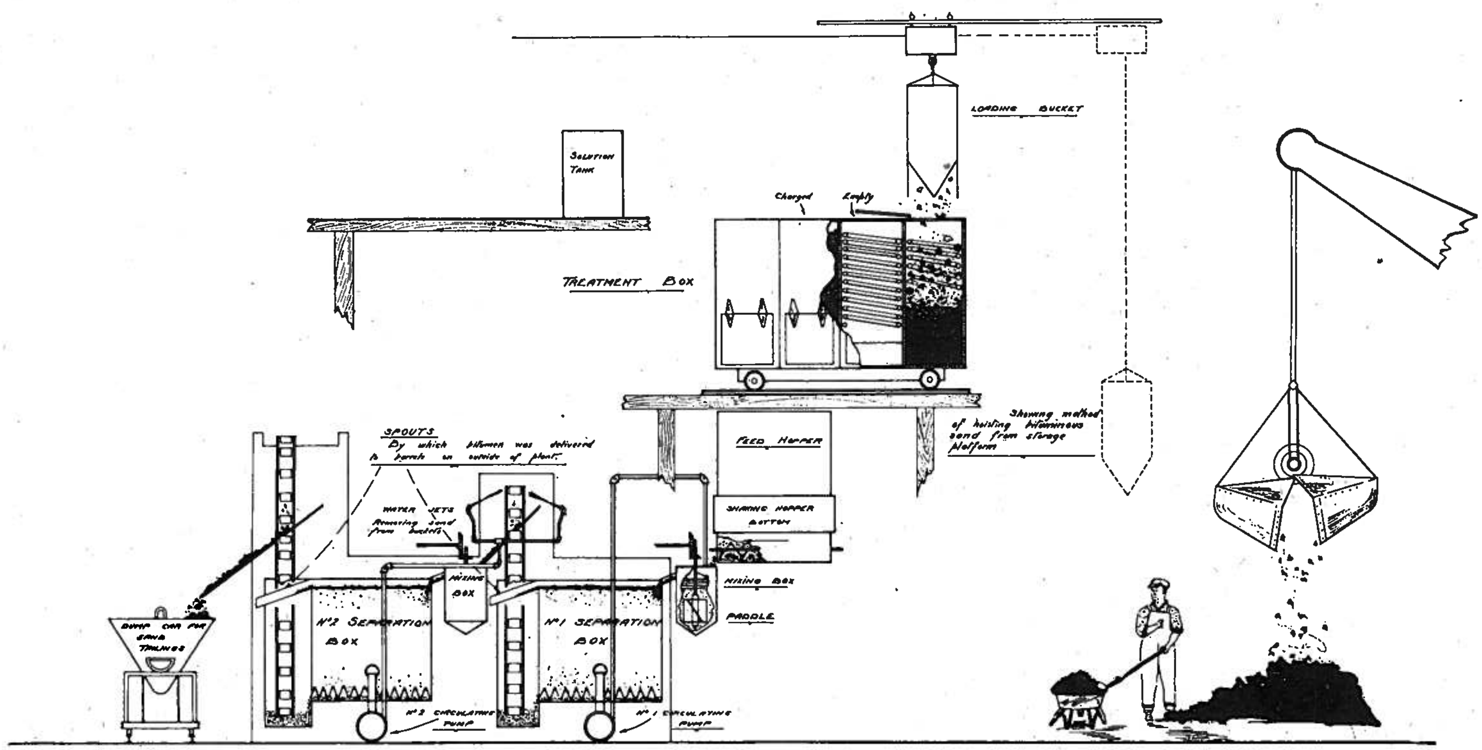

Figure 2.—The Bituminous Sand Separation Plant, 1924.

sump. A centrifugal pump circulated the hot water from the lower part of the separation box to the mixing box.

The plant was driven by a small steam engine, the exhaust steam from which was ample for all heating required.

Bituminous sand was bought from the McMurray Asphaltum and Oil Company. Carload shipments were spotted on the track beside the plant and unloaded onto a storage platform by means of the steam grab-bucket used in the railway yards for unloading coal. Bituminous sand from the stock pile was dumped into a skip and elevated to an overhead track running over the treatment box. The compartments of the treatment box were filled successively in this way and heated, after addition of the appropriate quantity of silicate of soda solution. When a fresh supply of material for separation was required, the treatment box was moved along its track to bring a compartment containing treated bituminous sand over the feed hopper of the plant and the contents of the compartment discharged into the hopper.

Dispersion of the treated bituminous sand into clean sand and fine drops of bitumen took place in the agitated hot water in the mixing box. The dispersed mixture overflowed with the water into the separation box where the sand dropped to the bottom in the comparatively still water, while the drops of bitumen floated to the surface forming a thick frothy layer which overflowed through a discharge outlet.

The sand tailings from the first separation box were retreated in a similar manner in the second unit where a further small amount of bitumen was separated.

Difficulties of Operation.

Trouble developed as soon as this plant was put into operation. It became evident that the design of the treatment box and of arrangements for charging it with bituminous sand and discharging treated material into the plant were poor. It was difficult to make the discharge doors of the treatment box compartments water-tight with the result that silicate of soda solution leaked away and failed to reach and treat much of the bituminous sand. The separation operations worked poorly as a consequence of inadequate treatment. The hoisting of bituminous sand by the skip, the emptying of the contents of the compartment into the feed hopper and the working of the material through the hopper into the mixing box proved cumbersome and unsatisfactory. About one hundred tons of bituminous sand were put through the plant, but the results were poor. Analyses of separated bitumen and sand tailings, in comparison with those of the products of the previous plant were as follows:

TABLE II.—COMPARISON OF 1923 AND 1924 RESULTS.

	1924.		1923.
	Best.	Average.	Average.
Crude Separated Bitumen:			
Water	18%	28%	29%
Bitumen	71%	42%	62%
Mineral Matter	11%	30%	9%
Sand Tailings:			
Bitumen	2.5%	4%	3%

Another difficulty became increasingly apparent as the 1924 operations were continued. The shipments of bituminous sand contained a considerable proportion of hard, weathered material from the face of the exposure from which the bituminous sand was excavated. The weathered material seemed to be particularly resistant to treatment and separation. The final shipment of the season consisted almost entirely of hard weathered lumps, and attempts at separation failed almost completely.

LABORATORY INVESTIGATION OF PLANT DIFFICULTIES.

Description of Laboratory Equipment.

The 1924 separation work was discontinued in October. It had become obvious by that time that the section of the plant for treating bituminous sand should be redesigned. Further, the experience with the weathered bituminous sand suggested that further study of the amenability of different grades of material to separation would be advisable. It was decided that the difficulties encountered should be made the subject of laboratory investigation during the winter and that the separation plant should be redesigned in the light of the results obtained.

Small scale separation equipment comparable to the separation plant, but with a minimum of mechanical complication, was set up in the laboratory. Figure 3 shows the general plan and arrangement of the various parts of the equipment. A galvanized iron box $4 \times 1\frac{1}{2} \times 1\frac{1}{2}$ feet was set up as a treatment box, into which three pails, each holding about fifty pounds of bituminous sand were placed. Water was placed in the large box and heated with a steam jet, thus forming a hot water bath for heating the bituminous sand in the pails. A large sized, power-driven meat mincer was used for studying the advantages of thorough maceration of the bituminous sand and the mechanical mixing of silicate of soda solution with it in connection with the treatment operation. A steam-heated and power-driven Werner and Pfleiderer Universal Kneading and Mixing machine was also set up for use for this same purpose. A galvanized iron box 16 inches wide, 24 inches long and 24 inches deep served as a separation box. In association with the separation box there was an 85-gallon steel drum for holding water which could be heated by a steam jet. Water from the drum was pumped into the separation box through an arrangement for giving a constant head and flowed back into the drum through a two-inch pipe arranged as shown in the diagram and allowing of an adjustment and regulation of the water level in the separation box. Two mixing boxes were attached to the separation box. One of these was similar to those used in the large plants; the other was a badly worn centrifugal pump connected to deliver below the surface of the water in the separation box. Observations during the plant operations in 1924 had suggested that more violent agitation in the mixing boxes was advisable. The motor driven rotor of an old pump offered a means of getting a much increased agitation. It was also thought that discharge of the dispersed bituminous sand below the surface of the water in the separation box would have advantages.

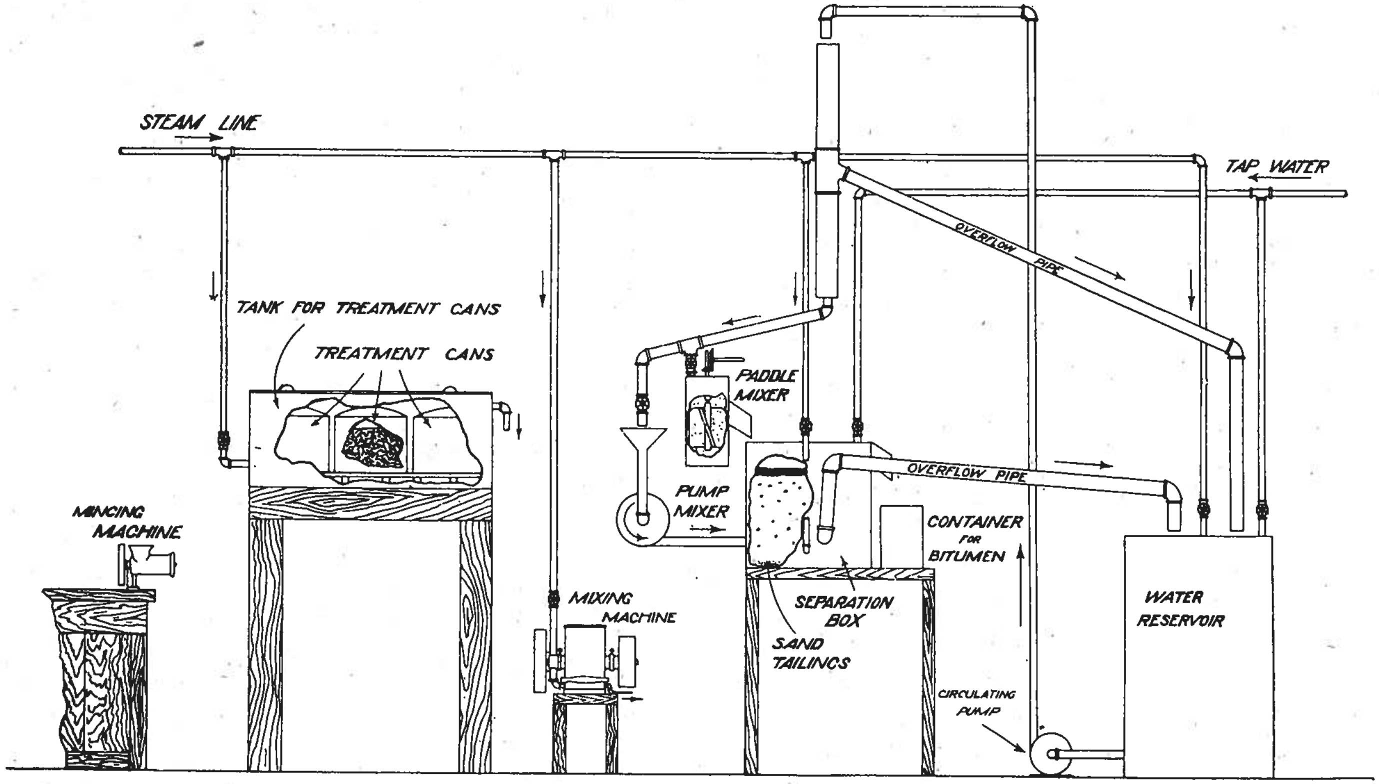

Figure 3.—Laboratory Separation Equipment.

Separation of Weathered and Unweathered Bituminous Sand.

The first matter studied by means of this laboratory equipment was the amenability of weathered bituminous sand to the separation process. A supply of bituminous sand from the carload shipments received during 1924 was brought to the laboratory. This included a quantity of material from the last shipment which had acted so badly in the separation plant.

Fify-pound lots of the general run of bituminous sand, containing both weathered and unweathered material, were placed in pails along with silicate of soda solution, and put in the hot water bath to heat and become treated. During the period of treatment, the bituminous sand and silicate of soda solution were put through the mincing machine to break down lumps to bring the solution into contact with all the sand. When the time of treatment had reached the desired duration, the treated material was put through the separation equipment.

As a further experiment a supply of bituminous sand was sorted as well as could be done into weathered and unweathered portions. Each type was tested in the way just described. Finally, samples of the last 1924 shipment of weathered lumps were used. The results of these runs are shown in Table III.

The results given in Table III show conclusively that weathered bituminous sand is not amenable to the separation process. This point does not introduce any serious practical difficulty into commercial separation work. It is only during the first stages of excavation of a bituminous sand exposure that weathered material would be encountered.

TABLE III.—SEPARATION OF FRESH AND WEATHERED MATERIAL.

(Bituminous sand treated with 20% by weight of 2% Silicate of Soda Solution.)

Material Treated	Treatment		Composition of Products				
			Separated Bitumen				
	Macerations	Time of heating, hrs.	Water %.	Bitumen %	Mineral matter %	Mineral matter dry basis %	Sand Tailings Bitumen %
Mixed fresh and weathered	1	28	26.0	68.0	6.0	8.0	1.4
Ditto	1	28	31.5	60.0	8.5	12.5	3.7
Ditto	1	24	25.0	52.0	23.0	31.0	2.2
Ditto	1	24	24.5	54.0	21.5	29.0	7.0
Ditto	1	24	26.5	63.5	10.0	13.5	3.0
Ditto	1	24	23.3	58.0	18.7	24.0	4.0
Weathered lums only	1	24	20.2	44.8	35.0	44.0	8.5
Weathered lumps removed	1	24	25.4	62.3	12.3	16.5	3.5
Ditto	3	24	25.8	67.9	6.3	8.5	3.3
Ditto	3	24	24.4	65.7	9.9	13.0	3.8
Ditto	3	24	25.4	67.1	7.5	10.0	2.2
Ditto	3	24	26.0	69.1	4.9	6.6	1.9
Last carload of 1924..........	3	60	21.0	44.8	34.2	43.0	7.4
Ditto	4	60	18.6	42.4	39.0	48.0	8.7
Ditto	6	60	20.0	49.9	30.1	38.0	8.6

In subsequent laboratory studies the weathered material was removed as completely as possible from the bituminous sand used.

Design of Mixing Box.

Trial separation runs to determine the advantage of violent agitation in the mixing box led to an unexpected and important result affecting mixing box design. It was found that a simple pipe down which a stream of hot water flowed, washing treated bituminous sand along with it into the separation box, gave sufficient agitation and was more effective than the former type of mixing box with agitating paddle. This fact was ascertained by using the arrangement into which the old centrifugal pump was built, and making runs both with the pump rotor revolving and stationary. Under the latter condition, the arrangement for introducing the treated bituminous sand into the separation box is virtually merely a pipe with several right angle turns.

In these experiments bituminous sand, freed from weathered lumps, was heated with silicate of soda solution in pails set in the hot water bath. Mincing was used to aid in the treatment. Heating was continued during one or two days. The treated material was then separated by running it into the separation box through the centrifugal pump with the rotor either driven at full speed by a motor or standing still. The results of the separation runs are shown in Table IV. The previous runs recorded in Table III were made using the mixing box with paddle agitation.

TABLE IV.—SEPARATION WITH AND WITHOUT MECHANICAL AGITATION.

Treatment		Composition of Products				
		Separated Bitumen				Bitumen Sand
Time of heating, hours	Agitation	Water %	Bitumen %	Mineral matter %	Mineral matter dry basis %	Tailings %
24	Yes	25.8	71.3	2.9	3.9	0.6
24	Yes	30.2	67.7	2.1	3.0	0.5
48	Yes	30.0	67.6	2.4	3.4	0.7
24	No	26.7	71.3	2.0	2.7	0.4
48	No	22.6	76.3	1.1	1.4	0.7
48	No	28.0	70.3	1.7	2.4	1.5

The Treatment Process.

Previous to the laboratory investigation now being described, the method of treating bituminous sand to prepare it for separation had been to place it in a container with enough silicate of soda solution to thoroughly soak it, but without excess, and then to heat to a temperature of nearly 100°C. for some hours. Mechanical mixing was not used for two reasons: it was feared that it would cause a premature separation of bitumen and lead to a poor quality of separated bitumen; and it was desired to avoid the use of unnecessary power. Moreover, a number of observations had been regarded as indicating that effective treatment required considerable time. The experience with the treatment end of the separation plant during 1924 showed that the simple operation of heating bituminous sand and solution together without mixing was not suited to large scale, continuous separation. It was too slow and cumbersome. The possibilities of treatment by mechanical mixing and heating were tested in the laboratory equipment. It was found that this form of treatment was thoroughly satisfactory and could be accomplished in a few minutes instead of in the hours previously required.

The steam jacketed mixing and kneading machine was used for the mixing and heating treatment. A charge of bituminous sand was placed in the mixer with the silicate of soda solution and mixed by the kneading action of the machine for 30 minutes. Steam in the jacket raised the temperature of the charge to 85° in about fifteen minutes. At the end of the mixing period the treated bituminous sand was put into a pail placed in the hot water bath to maintain its temperature, and separated at once, using the simple pipe and hot water stream arrangement for introducing it into the separation box. The results of runs with this form of treatment are shown in Table V in comparison with the results of runs for which the bituminous sand was treated by mincing through the meat mincer, or by both mincing and mixing in the Universal mixer with subsequent heating for a number of hours in the hot water bath. These results show that the quick treatment in the Universal mixing machine led to results that were as good as those obtained when the period of treatment was prolonged.

TABLE V.—COMPARISON MACERATION AND TIME TREATMENT.

Treatment		Composition of Products				
		Separated Bitumen				Sand Tailings
Maceration	Subsequent heating, hours	Water %	Bitumen %	Mineral matter %	Mineral matter dry basis %	Bitumen %
Minced	4	35.6	54.1	10.3	16	3.7
"	24	28.0	76.9	5.1	6	3.2
"	48	27.0	66.4	6.6	9	2.9
Minced and kneaded	6	27.6	70.2	2.2	3	0.5
Ditto	24	25.8	71.3	2.9	3.9	0.6
Ditto	48	22.6	76.3	1.1	1.4	0.7
Kneaded 30 minutes	....	24.3	73.4	2.3	3.0	1.3
Ditto	....	27.4	70.2	2.4	3.3	0.7
Ditto	....	21.4	76.8	1.8	2.3	0.9
Ditto	....	19.7	78.2	2.1	2.6	0.6
Ditto	....	24.0	73.2	2.8	3.7	0.8

SEPARATION PLANT OPERATIONS IN 1925.

Redesigned Features of Plant.

The treatment part of the separation plant was overhauled and rearranged in the spring of 1925 in the light of the laboratory studies. The new arrangement is shown diagrammatically in Figure 4. The treatment box and feed hopper of the 1924 plant were discarded and a second-hand, clay mixing machine substituted. The mixer was banked with steam coils and steam jets placed inside it. Pipes were arranged for running silicate of soda solution and water to the bituminous sand in the mixer as desired. The old hoisting skip arrangement for elevating bituminous sand into the plant was replaced by a bucket line which delivered into the mixing machine through a set of rolls. The old mixing boxes were replaced by three-inch pipe arranged as indicated in the diagram.

The rest of the plant remained essentially as before. Two innovations are worthy of mention, however. To facilitate the dumping of the fine, wet, sand tailings from the discharge bucket line, a knocker was installed which struck the chain and jarred the sand loose from the inverted buckets. The second modification was a slowly revolving wheel set over No. 2 separation box and dipping into the layer of bitumen froth on the surface of the water. So little bitumen accumulated in this separation box that it was difficult to make it flow out of a discharge outlet, but the revolving wheel collected it very effectively. A scraper removed the bitumen from the wheel and diverted it into a trough leading to storage. Such a wheel was not put into No. 1 box, but the arrangement worked so well in No. 2 that one would be installed if further separation work were undertaken.

Operation Results.

The rearranged plant was set in operation without difficulty and worked smoothly and satisfactorily throughout the season. The McMurray Asphaltum and Oil Company used all reasonable care to keep the proportion of weathered material in the shipment as small as possible, but because of the nature of the deposit being worked, and the relatively small amount of excavation, considerable weathered material was bound to be included in the bituminous sand loaded. Representative samples of the crude separated bitumen and of the sand tailings were taken daily. The average analysis for 75 samples was as follows:

Crude Separated Bitumen:	
Water	28%
Bitumen	65%
Mineral Matter	7%
Sand Tailings:	
Bitumen	2%

This shows a great improvement over the 1924 operations. Much of the bitumen remaining in the tailings was in the form of small lumps of weathered bituminous sand and the sand content of the separated bitumen was doubtless higher than it would have

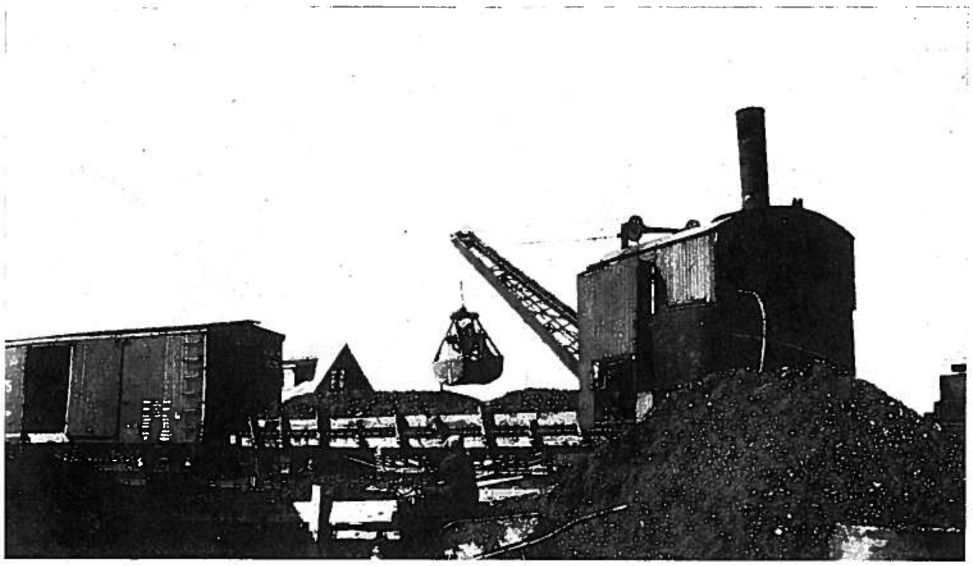

PLATE II.—Unloading bituminous sand with a grab bucket at the separation plant.

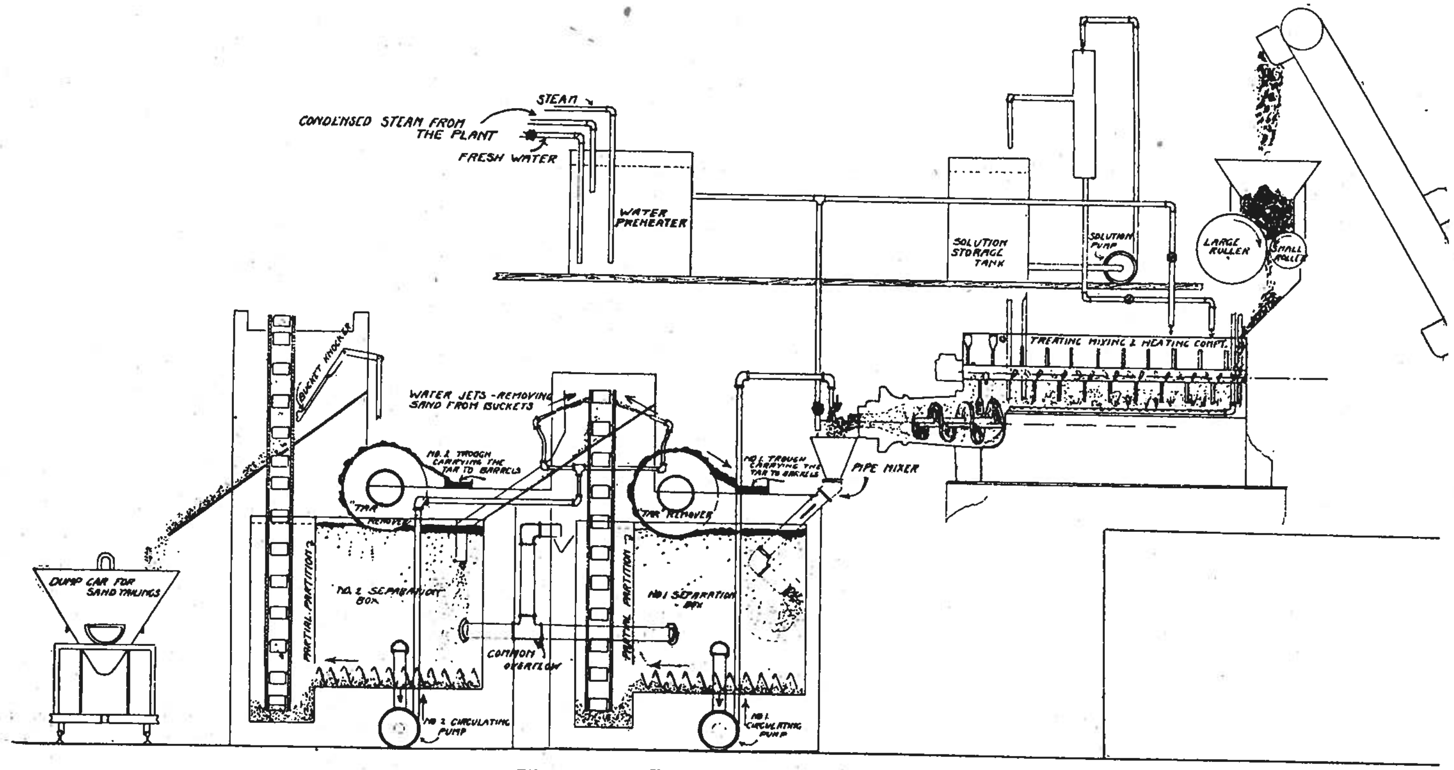

Figure 4.—Separation Plant, 1925.

been if no weathered material had been present. The sand tailings in the main were so free from bitumen that they dried out to a loose sand that blew off the tailings dump. This wind action left pea-sized lumps of weathered bituminous sand visible on the surface.

The program of separation of 500 tons of bituminous sand was achieved without difficulty. Most of the separated bitumen was used in a road construction experiment, as planned[14].

LABORATORY STUDIES, 1925-1926.

Experimental work with the laboratory separation equipment was continued during the winter of 1925-26. The immediate objective of the study was to demonstrate that the separation process was applicable to bituminous sand from all sections of the bituminous sand deposit. But other points were looked into and considerable additional general information gained about the separation process.

The separation work of previous years had all been with material from the southern part of the bituminous area. While it was a reasonable assumption that the process would work equally well on material from any other section, positive evidence was desired. Consequently a supply of material for separation studies was collected from a number of exposures along the Athabaska river as far as the northern limit of the area. One sample was taken from Ells river at a point about eight miles north-west of the Athabaska river at McKay. The samples were obtained after blasting into the face of the cliffs for a distance of about three feet to reach fresh sand, free from any weathering effect. Several hundred pounds were collected from each point. The samples were taken in the autumn when the weather was getting cold. This condition tended to prevent the material from drying out during the time that elapsed between excavation and the tests in Edmonton.

The location and general characteristics of the bituminous sand samples are given in Table VI.

The separation runs were made in the laboratory equipment described in a previous section, using the procedure that had been found most effective. The bituminous sand was treated by mixing and heating it with silicate of soda soluton for 30 minutes in the kneading and mixing machine and introducing it into the separation box by the pipe and hot water stream arrangement. The bitumen was separated from all five samples without difficulty. The results of the tests are given in Table VII. These samples show almost the full range of observed variability in regard to fineness of sand and specific gravity of bitumen. Consequently it can be asserted that the separation process is applicable to all grades of fresh, unweathered, bituminous sand from any section of the deposit.

Approximately eighty additional runs were made on the same supply of bituminous sand, and considerable information was obtained about the effect of conditions of operation of the separation

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14Sixth Annual Report of the Scientific & Industrial Research Council of Alberta, p. 55.

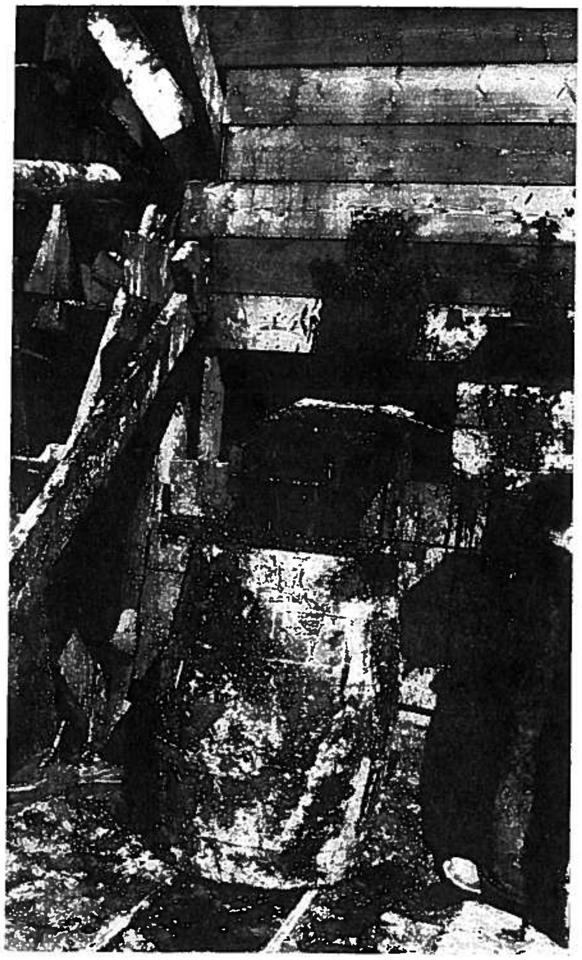

PLATE III.—Separated Bitumen Discharging from the Separation Plant.

TABLE VI.—SOURCE AND CHARACTERISTICS OF SAMPLES FOR TESTING AMENABILITY TO THE SEPARATION PROCESS.

Sample No.	Location of Point of Sampling	Composition of Sample			Screen Analysis of Mineral Matter				Specific Grav. of Bitumen Content 25°/25°C.
		Bitumen %	Mineral Matter %	Water %	Retained on Mesh 48 %	100 %	200 %	Passing Mesh 200 %	
1	8 miles below McMurray....	16.0	83.0	1.0	—	17	76	7	1.020
2	20 miles below McMurray....	11.1	88.0	0.9	9	69	18	4	1.022
3	Ells river, 12 miles upstream	....	....	0.6	....	4	69	27	1.008
4	35 miles below McMurray....	13.9	84.5	1.6	61	33	3	3	1.013
5	55 miles below McMurray....	12.7	86.3	1.0	....	4	86	10	1.013

TABLE VII.—RESULTS OF TESTS OF AMENABILITY TO SEPARATION PROCESS.

Tests were run on 17 lb. batches of bituminous sand in laboratory separation plant. Bituminous sand treated with 20% of 3% silicate of soda solution. Treatment temperature and temperature water 85° to 95°C.

Sample No.	Composition of Separation Products. Bitumen				Tailings
	Water %	Bitumen %	Mineral Matter %	Mineral Matter Dry Basis %	Bitumen Content %
1	22.5	75.1	2.4	3.2	1.5
2	21.0	87.0	2.0	2.2	0.6
3	28.2	70.3	1.5	2.1	0.8
4	21.1	77.1	1.8	2.3	0.5
5	16.9	80.3	2.8	3.4	0.6

Values for sample 1 are the average for 9 separation runs.
Values for sample 2 are the average for 3 separation runs.
Values for sample 3 are the average for 3 separation runs.
Values for sample 4 are the average for 4 separation runs.
Values for sample 5 are the average for 3 separation runs.

process. Rather than attempt a tabulation of the mass of figures representing the results of these tests, a brief summary of their principal indications will be given. They were as follows:

1. The effect of concentration of silicate of soda[15] solution used for treatment was not carefully studied. It was kept constant at 3% throughout most of the test runs. A number of runs with samples Nos. 3 and 5 were made, however, in which silicate of soda solution of 0.3% concentration was used. As good a separation resulted as with the more concentrated solution. This concentration corresponds to the use of 1.2 pounds of liquid silicate of soda per ton of bituminous sand treated.

[15] A commercial grade of silicate of soda sold by the Crown Soap Co., Calgary, Alberta, was used.

2. The conditions of plant operation must be adjusted to each type of bituminous sand treated in order to get the best separation results.

3. The temperature at which the bituminous sand is treated with silicate of soda solution and the temperature of the water in the separation boxes of the plant have a marked influence on the efficiency of the separation. The best temperatures lie within the range of 75° to 85°C.

4. Various salts dissolved in the plant water have a tendency to reduce the water content of the separated bitumen. The water content has been reduced in this way from 20 to 30% to less than 10% without sacrifice of cleanness of bitumen or of tailings.

5. Many observations strengthened the conviction that the separation process depends on the formation, properties and behaviour of bitumen emulsions of the water-in-oil and oil-in-water types and the inversion of the former to the latter.

CHAPTER III.

ESTIMATED COST OF SEPARATION.

A separation process must satisfy two general requirements to be commercially feasible. It must be adaptable to efficient, large scale work, and it must be economical in operation. The work already described has demonstrated that the process under discussion fulfils the first requirement. Regarding the second requirement, sufficient data are not available on which to base an accurate calculation of costs; but at least an approximate estimate can be made.

A plant of 1,000 tons per day capacity will be considered. It seems probable that operations of this size will be required to reduce unit costs to an amount approaching the minimum. Mining costs decrease rapidly as the quantity of material per day is increased. This is important since seven or eight tons of bituminous sand must be excavated for every ton of bitumen produced. Unit costs for separation would also tend to decrease as the scale of production was enlarged.

Bituminous sand can be excavated satisfactorily by steam shovel equipment. This has been demonstrated at Carpenteria, California, with bituminous sand very closely resembling the Alberta material. Two well-known manufacturers of steam shovel equipment, who were consulted, agreed that a ¾-yard shovel would be the smallest practical size suited to the Alberta deposits; but that this shovel would be satisfactory, and could dig 1,500 yards of bituminous sand in a 10-hour day. Using this and further infórmation supplied, the following estimate of excavation costs has been made.

BITUMINOUS SAND EXCAVATION COSTS.

¾-yard Steam Shovel, costing $15,000.
200-day working year, 10-hour day.

Daily Costs.

Interest at 8%, yearly depreciation at 10%		$13.50
Maintenance and supplies		1.75
Labour:		
Operator	$12.50	
Fireman	8.25	
Groundman	4.00	
Watchman	4.00	
		28.75
Fuel, 2½ cords wood at $4.00		10.00
Water, maintenance of pumping equipment		3.25
Total daily cost		$57.25

Cost per ton of Bituminous Sand Excavated (exclusive of removal of overburden and delivery of bituminous sand to separation plant).

100 tons per day	57 cents per ton
200 tons per day	29 cents per ton
500 tons per day	11 cents per ton
1,000 tons per day	6 cents per ton
1,500 tons per day	4 cents per ton

The cost of removing and disposing of overburden and of delivery of bituminous sand should not exceed the cost of actual mining. This will be the case at least for the more favourable locations available for first development projects. A total cost of 20 cents per ton for bituminous sand delivered to a separation plant appears to be a conservative figure for mining.

The cost of erection of a 1,000-ton per day bituminous sand separation plant can only be guessed at until such time as detailed plans are prepared. The experimental plant at the Dunvegan Yards could be rearranged with but little new equipment to have a capacity of 72 tons of bituminous sand per 24 hours. It could be duplicated for $6,000. By straight proportion of capacity and cost, a 1,000-ton plant would cost $200,000. Extra facilities not represented in the layout of the small plant and more expensive building conditions in the north country might offset the savings in construction of a large installation.

Depreciation at 20% per annum is assumed. For a new type of plant, untried commercially, replacements and repairs will be large.

Cost for heat and power is estimated at 15 cents per ton of bituminous sand separated. This is the average cost of the steam used for separation during the 1923 plant runs, based on the unit costs of the University of Alberta power plant.

The cost of silicate of soda for treatment is based on the addition of one ton of a one per cent. solution, of the ordinary commercial product, to every five tons of bituminous sand treated. This is equivalent to 1.6 pounds of solid silicate of soda per ton of bituminous sand. Solid silicate of soda could be delivered to Northern Alberta for about $75 per ton.

A working year of about 7½ months, or 200 days, and of 24 hours per day operation of the separation plant is assumed. It is further assumed that bituminous sand will be mined of sufficient richness to yield 14 lbs. of bitumen per hundred pounds separated. Large quantities of material of 15% to 16% bitumen content are available.

ESTIMATE OF COST OF PRODUCING SEPARATED BITUMEN.

Capacity of plant....................1,000 tons per 24 hours
Cost of Separation plant $200,000
Working year ....200 days
Grade of bituminous sand...........7 tons per ton of separated bitumen

Overhead.		
Interest at 8%	$16,000	
Depreciation at 20%	40,000	
		$56,000
Supervision and Labour.		
1 Superintendent	$3,000	
3 Engineers (1 per shift)	3,600	
12 Labourers (4 per shift)	8,640	
1 Mechanic (day only)	1,200	
2 Labourers (day only)	1,400	
		17,880
Heat and Power.		
15 cents per ton of bituminous sand		30,000
Silicate of Soda, 160 tons at $75		12,000
Mining and delivery to Plant.		
200,000 tons at 20 cents per ton....................		40,000
Total cost of 1 year's operation....................		$155,880

Tons of bitumen produced, 27,600.
Cost per ton, $5.65.
Cost per barrel of 350 lbs., $1.00.

No claim is made that this estimate is more than a first approximation of the probable cost of producing separated bitumen. Each item of the estimate is placed at a conservative figure, and experience indicates that the unit cost of one dollar per barrel of bitumen is high rather than low. The estimated cost of $5.65 per ton, or $1.00 per barrel of separated bitumen is evidence that the separation process besides being efficient is also economically possible.

CHAPTER IV.

MOTOR FUEL FROM SEPARATED BITUMEN.

The only use for separated bitumen that will be discussed here will be its use as a crude from which to manufacture motor fuel. Application of bituminous sand and of its bitumen to various types of road construction will be the subject of a separate report.

Rapid progress has been made, during the last few years, in adapting the cracking process and cracking equipment to the handling of heavy crude and residual oils, and it is reasonable, now, to think of the bitumen content of the Alberta bituminous sands as a crude oil from which motor fuel can be made commercially. In view of the new and changing outlook of the petroleum industry regarding suitable raw oils for gasoline manufacture, several of the prominent companies operating the cracking process were invited to make tests on samples of separated bitumen produced during the 1925 operations. The Universal Oil Products Company, owners of the Dubbs Cracking process, accepted the invitation. A ten gallon sample of the bitumen was sent to their laboratories at Chicago, Illinois. A summary of test results and comments follows[16]:

ANALYSIS OF CRUDE SEPARATED BITUMEN.

Crude Water-in-Oil Emulsion.

Specific Gravity	1.018
Water content	20%
Mineral Matter	(Not stated, but about 7%)

Dehydrated Crude.

Specific Gravity	1.031
Sulphur content	5.1%

Distillation Tests.

(100 c.c. charge)
Initial boiling point—350°F. (superheated)
End boiling point—658°F.

(600 c.c. charge)
Initial boiling point—285°F.
End boiling point—597°F.

Per cent. Over.	Temp. °F.	Per cent. Over.	Temp. °F.	Baume Gravity (A.P.I.)
5	460			
10	540	10	465	30.2
15	490			
20	505	20	583	29.6
25	572			
30	590	30	590	26.9
35	605			
40	608	40	563	27.1
45	655			
50	640	50	597	26.6
55	638			
60	618	60	585	27.0
65	595			
70	585			
75	583			
77	658			

[16]cf. also The Cracking of Bitumen from Canadian Alberta Tar Sands. Gustav Egloff and Jacque C. Morrell. Petroleum Times, Jan. 15, 22 and 29, 1927, and bulletin of same title issued by the Universal Oil Products Co., Chicago, Ill.

	Remarks
2% over at 410°F.	1.5% water.
23% over at 572°F.	3.1% over at 410°F.
77% distilled.	13% over at 572°F. (A.P.I. 29.8).
25% coke. (by weight)	40% Pitch bottoms.
2.5% water.	

A laboratory cracking test was made on a quantity of dehydrated bitumen with the following results:

LABORATORY CRACKING ANALYSIS OF DEHYDRATED BITUMEN

Charge	6,000 ccs.
Sp. Gr.	1,031
Pressure	90 lbs. per sq. in.

Products of Cracking Run.

	% Raw Oil
Pressure Distillate (Baume A.P.I. 38.8)	56.0
Residuum	None
Coke, Gas and Loss	42.3
(Coke—5.24 lbs.	
(Gas—37.85 cu. ft.)	
Water	1.7

Composition of Pressure Distillate.

		%Pressure Distillate	% Raw Oil
Gasoline (Navy End Point[1])		64.8	36.3
Baume Gravity (A.P.I.)	50.8		
Initial boiling point	114°F.		
End boiling point	437°F.		
Gas Oil		31.5	17.6
Baume Gravity (A.P.I.)	16.6		
Loss		3.7	2.1

Chemical Nature of the Gasoline.[17]

Unsaturated Hydrocarbons	27.2%
Aromatic Hydrocarbons	24.7%
Naphthene Hydrocarbons	12.3%
Paraffin Hydrocarbons	35.8%
Aromatic Hydrocarbon Equivalent	33.2%
Ricardo's compression Ratio	5.85

Coke and Gas Formation.

Coke—lbs. per gal	2.5
lbs. per bbl.	105
Gas—Cu. ft. per gal.	18.0
Cu. ft. per bbl.	756

The following comments were made on the tests:

"The dehydrated bitumen produced 25% of coke by weight by simple Engler distillation. Hence the only logical operation for gasoline production from this oil is no-residuum operation; that is, the production of coke, gasoline and recycle stock only, the gas being understood."

"36.3% of N.E.P. gasoline has been obtained from the cracking of the dehydrated bitumen, making in addition 17.6% of gas oil or pressure distillate bottoms. Recycling of this gas oil will make an additional 11% of gasoline based on the original dehydrated bitumen, which will bring up the ultimate yield from the cracking of

[1] Gasoline meeting the U.S. Government specification for motor gasoline.

[17] cf. Ind. & Eng. Chem. 18, 354 (1926) for method of Egloff & Morrell for estimating the various groups of hydrocarbons.

the bitumen to between 45 and 50%. This may be obtained in a single operation by removing end point gasoline from the cracking still."

"The cracked distillate may be readily treated into marketable gasoline by the use of the simplest acid and plumbite method." (A brief description of the treatment procedure was given in their report.)

"The cracked gasoline is very high in anti-knock properties, having an aromatic hydrocarbon equivalent of 33.2; that is, the motor equivalent of a straight run Mid-continent gasoline containing over 25% of commercial benzol in admixture. The gasoline is highly superior to the average motor fuel in anti-knock qualities."

The following questions were asked the Universal Oil Products Company when the sample of separated bitumen was sent for test:

1. What would be the nature and value of the residue from the bitumen after cracking?
2. What effect will the water and mineral matter content of the crude separated bitumen have on the handling of it in commercial cracking equipment?
3. What would be the approximate cost of cracking the bitumen and refining marketable products?

The answers given were as follows:

1. "Regarding the nature and value of the residues: where a coke is the only residue, it may be used for fuel purposes, being very high in quality in that respect. The coke formed from the cracking of the bitumen has a very high calorific value, being between fifteen and sixteen thousand B.T.U.'s per pound. As the mineral matter in the bitumen is a variable, the ash in the coke will vary likewise. In the event that the operation is of the liquid residue type, a liquid fuel of any desired characteristics may be produced. Coke will also be a product of this type of operation."

2. "The question of water and mineral matter in the oil will not affect the commercial cracking of same to any extent which would prevent consideration of cracking. In the event that it is too costly or too difficult to remove the water and mineral matter by pretreatment, a heat exchanger may be used in conjunction with the cracking unit. Further than this, the question resolves itself to design of the cracking plant so as to obtain the velocity required to prevent settling of the mineral matter in the tubes. The question of the removal of water is one that has been definitely settled upon a commercial scale, and the Dubbs Process is today handling charging stocks direct containing several per cent. of water together with mineral matter."

3. "The present cost of refining the cracked distillates as outlined above, will be between 25 and 30 cents per barrel of gasoline product. The cost of refining depends mainly upon marketing conditions, *e.g.*, the question of meeting specifications such as water-colour, doctor sweet, and negative corrosion gasoline. When these specifications are not rigid, it may be reduced beyond that shown

above, but this cost is based upon a product meeting all of these specifications. This figure does not include the cracking of the charging stock, which will be in the neighbourhood of 50 cents per barrel."

Almost unlimited scope for bituminous sand development can be seen as soon as the supply of good grade crude oils begins to fall off, or to rise in price, and the oil industry turns to other raw material for motor fuel manufacture. Already the problem of supplying future needs for crude oil is being considered in discussions and studies of methods of reclaiming the petroleum remaining in exhausted oil fields, the retorting of oil shales and the conversion of coal into oil. The working of the Alberta bituminous sands should be among the first activities to be undertaken to supplement oil supplies. This material involves a minimum of difficulties. The supply of bituminous material is in plain sight and is of enormous extent.[18] Its mining would be a simple project. The bitumen is present in the bituminous sands as a mixture which can be resolved by simple means. No profound thermal decomposition of organic matter is required as is the case with oil shales. An efficient and economical method for separating the mixture of bitumen and sand is available. And, finally, industry is already using processes which are directly applicable to the conversion of the bitumen into motor fuel.

It will require but a small diminution in the supply of crude oil or increase in the demand for gasoline to render possible the development of the Alberta bituminous sands for the production of motor fuel. If, as appears to be the case, separated bitumen can be produced for a dollar a barrel, and can be turned into a forty-five per cent. yield of cracked gasoline, conditions in the near future should cause a profitable basis for an industry. On the other hand, prospecting may reveal extensive petroleum pools in Western Canada which would cause a delay in bituminous sand development. The results of search for oil fields to date does not give strong hopes that this will happen. It is not improbable that the great bituminous sand deposit represents Nature's major gift of crude oil to Western Canada, and that it must be turned to as the source of supply of mineral oil products for the Prairie Provinces.

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[18]cf. Part I of this report for information about the extent and nature of the bituminous sand deposits.

CHAPTER V.

CONCLUSION.

The studies described in this report have given a process for separation of the bituminous sands by means of hot water, which is efficient and economical. A separation plant has been built and operated which was of sufficient capacity to demonstrate that the process can be applied to large scale work. Experience with this plant has shown further the type of equipment and plant design that is suitable for the handling of large quantities of bituminous sand. There is much yet that can be suitably done by a government laboratory to add to the information already gained about the process and how it can be best carried out, and such studies are planned. But the adapting of the process to actual commercial separation, and the solving of the practical difficulties that inevitably will arise when this is undertaken, must be left to private enterprise. A company prepared to establish a new industry should have no serious difficulty in carrying the separation process forward to commercial success from the stage where it now rests. The main difficulties have been solved. Good engineering will finish the task.

Laboratory study of the process is being continued, in particular, investigations of emulsions of the bitumen with water. The separation of the bitumen and sand appears to depend on the formation and behaviour of such emulsions. If the conditions under which the water-in-oil and oil-in-water types form, invert and break can be determined, the best conditions for the carrying out of the process will become known and useful information affecting details of plant design may result. It is hoped that such study will reveal a simple way of preventing or eliminating the high water content of the separated bitumen. This water is the principal remaining difficulty of the process. Evidence that this can be accomplished is provided by results of laboratory runs in which the water content was reduced to less than 10% by introducing electrolytes into the plant water. The water which is retained by the bitumen on separating is probably subject to control by the manipulation of the factors known to affect colloid systems.

Report No. 18

Scientific and Industrial Research Council of Alberta

The Bituminous Sands of Alberta

BY

K. A. CLARK

PART I. OCCURRENCE.
PART II. SEPARATION OF BITUMEN FROM SAND.
PART III. UTILIZATION.

PUBLISHED BY AUTHORITY OF THE HON. J. E. BROWNLEE
Chairman of the Scientific & Industrial Research Council of Alberta.

EDMONTON:
PRINTED BY W. D. McLEAN, KING'S PRINTER
1929

Report No. 18

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The Bituminous Sands of Alberta

BY

K. A. CLARK

Road Materials Division.

PART III. UTILIZATION.

A Study of the Commercial Possibilities of Various Uses for Bituminous Sand.

ORGANIZATION

The Scientific and Industrial Research Council of Alberta, formed in January, 1921, carries on its work in co-operation with the University of Alberta.

The personnel of the Council at the present time is as follows:

Hon. J. E. Brownlee, Premier of Alberta, Chairman.

R. C. Wallace, President, University of Alberta.

Hon. O. L. McPherson, Minister of Public Works.

J. A. Allan, Geologist.

N. C. Pitcher, Mining Engineer.

R. W. Boyle, Dean, Faculty of Applied Science, University of Alberta.

R. M. Young, Canmore, Alberta.

Edgar Stansfield, Honorary Secretary, University of Alberta.

Requests for information and reports should be addressed to the Honorary Secretary, Industrial Research Department, University of Alberta, Edmonton, Alberta.

LETTER OF TRANSMITTAL

HONOURABE J. E. BROWNLEE,
Premier of Alberta,
Edmonton, Alberta.

Sir:

I have the honour to transmit herewith a report entitled "The Bituminous Sands of Alberta", Part III.

The Scientific and Industrial Research Council instructed me to compile the results of our work on the bituminous sands for publication. Part I of the general report, dealing with the occurrence of the bituminous sands in Northern Alberta and our field examination of the deposit, has been published. Part II, dealing with our study of a method for separating the bitumen from the bituminous sands, has also been published. The present report, Part III, deals with the use of bituminous sand and of separated bitumen for road construction and discusses the commercial possibilities of the various uses to which bituminous sand can be put. Special attention is given to the possibilities of gasoline manufacture.

Respectfully submitted,
K. A. CLARK,
Research Engineer, Road Materials.

Department of Industrial Research,
University of Alberta,
Edmonton.

April 4th, 1929.

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The Bituminous Sands of Alberta

BY

K. A. Clark

PART III.

UTILIZATION.

CHAPTER I.

INTRODUCTION.

The bituminous sand studies of the Scientific and Industrial Research Council of Alberta have been directed along three general lines. The deposits have been investigated in the field with respect to their accessibility, variability and other economic features. A process has been developed in the laboratory and in experimental plants for separating the bitumen from the sand. And tests have been made for demonstrating practical uses to which the separated bitumen may be put, particularly in connection with highway construction. The results of studies along the first two lines have been given in Parts I and II of this general report on the Bituminous Sands of Alberta. The present Part III contains the results of the remaining line of work. It is in the main, however, an economic study of the possibilities of the various ways of commercially developing the bituminous sands.

Few have doubted that the immense deposits of bituminous sand in Northern Alberta would, eventually, be turned to practical use and form the basis for industry. There has been considerable uncertainty, however, about the form that development would take. Various uses for the material have been recognized as possible. The raw bituminous sand can be used directly for the preparation of pavement aggregates. The bituminous content of the sands can be extracted and used either as an asphalt, principally for road construction of various types or as a crude oil for manufacture of petroleum products. But so long as these uses were all obviously matters of the future, there was little use of considering them in detail. Everything depended on the turn of events in the realm of economics during the period that had to elapse before bituminous sand development became a real possibility.

The general opinion has been that the use of the bituminous sand itself and of the bitumen extracted from it for pavement and bituminous highway construction would be the use that would first have sufficient practical application to warrant development. Use of the bituminous sand as a source of petroleum products, particularly gasoline, was regarded as a remote possibility. However, advances of great significance have been taking place in the technology of the petroleum industry and have changed the outlook in this latter direction. The conversion of heavy oils into high yields of gasoline is now a matter of every day commercial operations. There is no particular technical obstacle in the way of using the bitumen content of the bituminous sands as a crude oil and this use must be placed along with that of road materials for present consideration. Which offers the best opportunity for commercial development is a matter almost entirely of economics. It is consequently of importance to examine each possible use from this standpoint.

Uses for bituminous sand which have been suggested as a basis for commercial development are discussed in the pages that follow. The general background and present technical status of each is sketched and then the economic factors into which its employment must fit are considered. This treatment leads to the conclusion that the use of bitumen separated from the bituminous sands for gasoline manufacture is the application in sight which has sufficient possibilities to form a basis for an *extensive* bituminous sand industry, and that conditions in Western Canada are such as to make this application well worth serious consideration for the immediate future. Use of the separated bitumen as a road oil for rural road construction is rather disappointing on close examination. In spite of the large quantities of oil that will be used on the roads in the area in which the bitumen might compete, these quantities are nevertheless not large enough to allow of bituminous sand development on a sufficient scale for economical, low-cost operation. Use of the separated bitumen prepared in the form of asphalt emulsion for road and other construction work has better possibilities. In view of the fact that asphalt emulsions are coming into favor rapidly and that the bituminous sand deposit is about the only source for a domestic supply of asphalt for Western Canada, there is good prospect that there will be a large enough demand for emulsified bitumen to make economic and profitable bituminous sand development possible. Preparation of emulsion would be a simple and convenient way of inaugurating development work which would lead on to the larger and more alluring field of gasoline manufacture.

CHAPTER II.

BITUMINOUS SANDS FOR PAVEMENT CONSTRUCTION.

CRUDE BITUMINOUS SAND AS A PAVING MATERIAL.

Pavement construction has been among the first thoughts which have come into the minds of all who have considered the practical possibilities of the Alberta bituminous sands. The idea is an obvious one since this is the outstanding use to which rock asphalts and bituminous sands throughout the world have been put. The first bituminous pavements were made with the asphalt-impregnated limestones of Europe. Similar deposits are found in America. Bituminous paving in California commenced with the use of bituminous sand very closely resembling the Alberta material. The bituminous limestones and sandstones that occur in Oklahoma, Texas, Utah and Kentucky have all been used for paving work. Refined asphalt cheaply produced by the petroleum industry and the development of the synthetic types of pavements prevented the growth of a rock asphalt industry in America. However, its use was never entirely displaced and at the present time appears to be regaining favor.

Pavement Construction Using Bituminous Sand.

A considerable amount of pavement has been built with the Alberta bituminous sands. The history of this work has been given in Part I of this report[1] and need not be repeated. Two additional projects have been carried through recently and should be noted. The Department of Mines and the Parks Branch, Department of the Interior, Ottawa, together with the Canadian National Railways co-operated during 1926 and 1927 in the surfacing with bituminous sand aggregate of about three miles of gravelled highway between the railway station and the Canadian National Hotel, known as Jasper Lodge, at Jasper in the Jasper National Park, Alberta. Driveways and sidewalk surfaces around Jasper Lodge were also built.[2] This demonstration work has received wide notice and favorable comment. During 1927 a driveway on the grounds of the government buildings at Edmonton was surfaced with pavement aggregate made from the bituminous sands. This latter work was done by the McMurray Asphaltum and Oil Co. under the supervision of Mr. Thomas Draper.

Technology of Constructing Pavements from Bituminous Sand.

The technical problem of making pavement with bituminous sands resolves itself into that of modifying the composition of this raw material in such a way as to make it conform with whatever is adopted as the standard composition of the aggregate to be laid as pavement surfacing. Such standard will call for a mineral aggregate falling within certain limitations as regards mechanical

[1]Part I, this report, p. 8.
[2]"Use of Alberta Bituminous Sands for Surfacing Highways." S. C. Ells, Report No. 684, Mines Branch, Dept. of Mines, Ottawa.

grading, properly mixed with a definite proportion of asphalt of specified consistency. Raw bituminous sand will vary with respect to all these points of definition of the standard aggregate. Since the grades of material that would be shipped for paving work contain more bitumen than required, extra mineral aggregate must be added and this can be chosen so as to modify the total aggregate of the final mixture toward the grading desired. The consistency of the asphalt content of the raw bituminous sand can be hardened by distilling off a portion of it in a heating operation. The aggregates so far used in paving work have been prepared by charging bituminous sand and a determined quantity of mineral aggregate into a heated rotary mixer and heating the charge for the period of time and up to the temperature considered proper for hardening the asphalt content of the bituminous sand sufficiently for the purpose of the pavement. The laying of the hot aggregate on the road has been done by the ordinary procedure used in standard practice.

No standardization of design of bituminous sand pavement aggregates has been made as yet. Experience with the material is still too meagre. The demonstration pavements of the Dominion Department of Mines have been fashioned after standard types. The three sections of the Edmonton experiment[3] consist of aggregates made to approximate the composition of sheet asphalt, bituminous concrete and bitulithic pavements. The aggregate used for the highway at Jasper is described as a stone-filled sheet asphalt.[4] The actual batches of aggregate turned out by the mixing plants used on these projects showed considerable variation in the grading of the mineral aggregate and percentage of asphalt and especially in the consistency of the asphalt. All analyses reported showed that the asphalt was too soft for penetration measurements under the standard conditions used for this test. The pavements are behaving well in service. Consequently it appears that the imposing of the specifications used in standard pavement construction practice is not warranted. What limitations should be made, however, to ensure good results from the use of bituminous sand is still an open question.

Basis of Sale of Bituminous Sand for Pavements.

The introduction of bituminous sand for making pavements means the placing of this material into successful competition with those already in use in the paving business of Western Canada. This can be accomplished if bituminous sand can be offered to the market at a price that is substantially less than the cost of its equivalency of materials now in use and if enough of it can be sold to make the supplying of it a profitable undertaking. A judgment as to the possibilities of fulfilling these conditions depends on the facts regarding costs and extent of markets.

Bituminous sand must be regarded, from the business standpoint, as simply an alternative source for the sand and asphalt generally used in making pavements and must be sold on this basis. Ordinarily, the sand is secured from the nearest suitable pit. The

3Cf. "Bituminous Sands of Northern Alberta." S. C. Ells, Report No. 632, Mines Branch, Dept. of Mines, Ottawa, p. 75; also this report, Part I, p. 8.
4loc. cit. p. 24.

asphalt, refined so as to have the required physical properties of consistency, etc., is secured from the petroleum refineries. The materials are combined in accordance with well developed principles of design, and heated and mixed together in an asphalt plant. If bituminous sand is used, all the asphalt and most of the sand are secured as a mixture and neither material will be exactly what is required for the final pavement aggregate. These faults are corrected by admixture of local sand or stone or both along with a heat treatment in an asphalt plant. The final pavement aggregate in the case of each set of materials are comparable and the finished pavement surface is made from both by the same procedure. The lack of choice of selection when asphalt and sand are supplied together as bituminous sand may be a disadvantage while the thorough natural mixture of the two may be an advantage. The bituminous sand possesses no obvious superiority over local sands and refined asphalt. Consequently, the deciding factor in the choice between them must be that of relative price.

Competitive Value of Bituminous Sand.

The value of refined asphalt and local sand equivalent in amounts to those present in a ton of bituminous sand can be approximately determined. This value will indicate the upper limit of price at which bituminous sand can be sold as a paving material. It will be assumed that a rich grade of material containing 15% by weight of bitumen[5] would be offered to the market. A ton of it would consequently contain 300 pounds of asphalt and 1700 pounds of sand. At Edmonton, local sand for sheet asphalt costs $1.75 per yard delivered to the city asphalt plant. Refined asphalt costs $31.50 per ton. Giving the same value to the bituminous sand constituents, 1700 lbs. of sand are worth $1.10[6] and 300 pounds of asphalt are worth $4.75, making a total of $5.85. This calculation makes no allowance for loss of weight of asphalt due to distilling some of it away in the asphalt plant.[7] On the other hand, neither does it allow for the presence of some mineral matter passing the 200 mesh sieve which might be valued at the price of portland cement as filler. At Calgary sand costs $2.50 per yard and refined asphalt cost $34.50 per ton in 1928. The corresponding value of a ton of bituminous sand is $6.75. At Winnipeg sand costs $1.50 and refined asphalt cost $29.50 in 1928. The corresponding value of a ton of bituminous sand is $5.35 per ton. These are the only cities in Western Canada that are doing an appreciable amount of paving. The average of the equivalent values for Edmonton, Calgary and Winnipeg is $6.00 per ton. This value can be taken as an indication of the maximum competitive price at which bituminous sand can be marketed.[8]

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[5]Cf. Part I, p. 63. Bituminous sand containing 15% bitumen is exceptionally rich material.

[6]A cubic yard of the sand is considered as weighing 2700 pounds.

[7]Cf. Part II, p. 3 and footnote.

[8]Cf. "Bituminous Sands of Northern Alberta." S. C. Ells, Report No. 632, Mines Branch, Department of Mines, Ottawa, p. 82. Ells calculates an equivalent value for bituminous sand varying from $5.98 to $7.39 depending on whether it is used to make sheet asphalt, bituminous concrete or bitulithic aggregate. Such a result is obviously in error. The mistake arises because Ells does not compare bituminous sand aggregates and aggregates made from alternative materials that have the same composition. The right equivalent value for bituminous sand on the basis of the Edmonton prices he quotes for sand and asphalt is about $5.95.

It is not reasonable to suppose that bituminous sand can be sold in competition with the materials now in use on an equal price basis. Pavement engineers cannot be induced to acquire new asphalt plants and face the problems of a new material unless a real saving in costs can be accomplished by doing so. Those interested in the matter can form their own judgment about how much less than the equivalent value of $6.00 per ton, bituminous sand would have to be offered to the market to secure sales. Whatever this price is, it must include the cost of mining, freight charges to the place where it is sold, incidental expenses and the profit on the business.

Cost Factors in Marketing Bituminous Sand.

Mining costs have been discussed in Part II of this report.[9] Steam shovel excavation was considered during a 200 day working year. The cost of the actual mining of the sand was found to be in inverse proportion to the quantity mined per day and varied from 57 cents per ton for 100 tons per day to 4 cents per ton for 1500 tons per day—the capacity of the shovel. These figures did not include cost of removing overburden nor overhead due to investment in bituminous sand property. For operations on the scale of 1000 tons per day under good conditions, a total cost of 20 cents per ton was arrived at as a conservative estimate. On the other hand, if the scale of operation was 100 tons per day, the cost per ton would be at least $1.00, if not considerably higher.

So far, bituminous sand has been classed as 10th class freight by the Canadian National and Canadian Pacific Railways. The Alberta and Great Waterways Railway has made a special commodity rate of 20½ cents per 100 pounds or $4.10 per ton for hauling bituminous sand the 300 miles from Waterways to Edmonton. In the United States the rock asphalt producers have succeeded in getting their product shipped at common sand and gravel rates. This should be good precedent for asking for a similar concession for Alberta bituminous sand. Table I shows the freight charges on a ton of bituminous sand from Waterways to a number of cities and towns in Alberta and the other prairie provinces based on the prevailing rates for bituminous sand and on the sand and gravel rates.

TABLE I.—FREIGHT CHARGES ON A TON OF BITUMINOUS SAND FROM WATERWAYS TO VARIOUS POINTS IN ALBERTA, SASKATCHEWAN AND MANITOBA BASED ON PRESENT BITUMINOUS SAND AND ON COMMON SAND AND GRAVEL RATINGS.[10]

Point	Distance Miles	10th Class	Sand and Gravel Class
Edmonton, Alta.	300	$ 4.10	$ 2.20
Calgary, Alta.	495	8.30	4.00
Lethbridge, Alta.	618	9.30	4.40
Medicine Hat, Alta.	668	9.90	4.60
Saskatoon, Sask.	627	9.50	4.40
Swift Current, Sask.	807	11.30	5.20
Moose Jaw, Sask.	775	11.10	5.00
Regina, Sask.	784	11.10	5.00
Brandon, Man.	1006	13.10	5.90
Winnipeg, Man.	1094	13.70	6.10

[9]Cf. Part II, p. 29.
[10]Table I has been compiled from data supplied by the freight departments of the Alberta and Great Waterways and the Canadian Pacific Railways at Edmonton.

The Market in Western Canada for Pavement Asphalt.

The market for bituminous sand as a paving material would be provided, at present and for some years to come, entirely by the cities and a few large towns. No paving of rural highways is being done and there is small reason for supposing that any appreciable amount will be done during the next ten years. The main highway systems are now in process of being constructed to a good standard of graded earth roads with gravel surfacing. Rural pavements are well down in the list of anticipated rural highway improvements. Regarding urban paving work, the activities of the past five years in the cities and towns mentioned in Table I are shown in Table II.

TABLE II.—USE OF ASPHALT FOR PAVING WORK DURING THE LAST FIVE YEARS IN THE PRINCIPAL CITIES AND TOWNS OF THE PRAIRIE PROVINCES.

	Tons.	Per ton.
EDMONTON:		
1924	226	$31.80
1925	278	34.66
1926	644	34.80
1927	239	34.80
1928	704	31.50
CALGARY:		
1924	159	$36.50
1925	177	36.50
1926	275	39.80
1927	316	35.50
1928	650	34.50
WINNIPEG:		
1924	837	$27.00
1925	969	33.63
1926	1102	33.63
1927	2127	32.73
1928	1850	29.42

Lethbridge Medicine Hat Saskatoon Swift Current Moose Jaw Regina Brandon	These places combined probably did not use 100 tons of asphalt for paving during the last 5 years.

Edmonton and Calgary combined used 1,354 tons of asphalt during 1928. If all this asphalt had been supplied in the form of bituminous sand of 15% by weight bitumen content, 9,000 tons of it would have been required. A plant of sufficiently large scale to operate at low unit costs would turn out this quantity of material in one to two weeks. Spread over the season, it would keep a 45 ton per day plant busy for 200 days.

BITUMINOUS SAND PREPARED AS A READY-MADE PAVING MATERIAL.

There is another way of placing bituminous sand on the market which differs somewhat from that just discussed. So far, bituminous sand has been considered as a natural, variable mixture of asphalt and sand which may be used in place of refinery asphalt and clean sand from local sources. Its use necessitates a mixing plant and leaves the responsibility of blending it properly with additional sand and stone and heat-treating it, to the consumer. The alternative way of marketing bituminous sand is for the producer to shoulder this responsibility and offer for sale a standardized, ready-made pavement aggregate which can be placed on the roadway and rolled into finished pavement directly from railway cars without need of mixing or heating operations.

Kentucky Rock Asphalt.

The Kentucky rock asphalt industry is based on this procedure. It exploits deposits of sandstone impregnated with from 5% to 10% by weight of a soft asphalt. Use of the material for making pavements dates back many years. Some of the early pavements were excellent and others were not so good. Examination into the cause of variable results revealed the fact that the good pavements were all made with asphaltic sandstone of about 7% bitumen content. Consequently, in reviving the use of this material during recent years, great care has been taken to control the asphalt content of shipments close to this value. The sandstone is blasted out in quarries, sorted over by hand and delivered to the mill in lots that will average 7% in bitumen content. The quarrymen, closely checked in their judgment by laboratory analyses of finished product, become sufficiently expert and accurate in sorting the rock sent to the mill. The milling consists of crushing which breaks down the mineral bond of the sandstone and reduces it to a bituminous sand. The crushing to successively finer sizes is so ordered as to introduce an effective mixing and to smooth out variations in bitumen content. The final product is placed in a stock pile where a further distribution of bitumen to a uniform value takes place. Every precaution is taken to maintain a standard composition for the aggregate shipped for construction work. Consequently, uniformly good pavements result from its use and it is winning a growing popularity. In 1926, the Kentucky Rock Asphalt Co. was mining and selling close to 1000 tons of material per day. The product sold for about $8.00 per ton at the company's plant and was being shipped throughout a territory of many hundreds of miles radius.

The principal sales claim for Kentucky rock asphalt is that its use requires no heating and no asphalt paving plant. It is placed on the roadway as received during warm summer weather and rolled down into finished surface. Cities find the rock asphalt convenient for small repair work. Thriving towns that have no asphalt plant but which want some paving on main streets see a simple way through their problem by using the ready-made material. It is not cheap. But it is handy and gives good results.

Ready-Made Paving Material from Alberta Bituminous Sand.

Alberta bituminous sand could not be worked up into ready-made paving aggregate in just the same way as is done with Kentucky rock asphalt. But there is no reason to suppose that a similar result could not be arrived at. Rich bituminous sand could be shipped to a plant favorably located with respect to supplies of sand and crushed rock and markets, prepared into a uniform standardized aggregate and reshipped to points of sale. Some careful research would be required in arriving at the composition of the standardized aggregate and in working out a plant and procedure which would produce the uniform product. This, however, should involve nothing particularly difficult.

Marketing Conditions.

The marketing conditions under which the ready-made aggregate would have to be sold are much the same as those for bituminous sand as a raw paving material. The former should bring a better price, but on the other hand it would cost more to produce. It is a fact that large amounts of similar aggregates are being bought in the United States for as much as $8.00 a ton and freight charges often for many hundreds of miles haul paid in addition. Refinery asphalt is cheaper in most places in the States than it is in Western Canada. Yet it is difficult to see how the material could be marketed as favorably on the Canadian prairies. The cities possessing asphalt plants can prepare their own aggregate for about $6.00 per ton for materials plus an additional charge for operating the plant. Interest on the plant investment must be paid in any case and engineers and foremen for doing the work are on the city pay rolls. It would seem as though it would require a very persuasive form of salesmanship to induce these cities to pay American prices for ready-made pavement aggregate. The situation is rather different in the case of large towns that have no asphalt plant and which wish to do some paving. Such towns are not numerous in Western Canada and their needs for materials will not grow to large dimensions for some years yet.

CHAPTER III.

SEPARATED BITUMEN FOR ROAD OIL.

Use for building pavements is only one of the possibilities of bituminous sand as a road material. Its bitumen constituent is an asphaltic oil which may be adapted to construction of the whole range of bituminous roads. The oiled earth and oiled gravel road types come in this category and are of particular interest to Western Canada in its present stage of rural road development. Since the problem of separating the bitumen from the sand is no longer a serious obstacle, the use of the separated bitumen as a road oil should be considered as a possible basis for bituminous sand development.

The Earth Road Problem.

Although the earth road must continue to be the prevailing type of highway on the hundreds of thousands of miles of road allowances on the thinly populated prairies, there is a constant urge to have something better. Gravel deposits are few and far between, and even though diligent search is revealing much more of this material than was supposed to exist, long, expensive hauls are generally necessary to get it on the highways. Gravelling is being done to an increasing extent each year on the main highways. Some alternative and less expensive improvement would be very useful specially for the less travelled but important market roads.

Earth Road Oiling in Illinois and California.

Similar problems have been met in other parts of the continent and the ways in which they have been handled are suggestive of what might be done in the prairie provinces. The State of Illinois has practically no gravel for surfacing the endless miles of roads through its agricultural counties. The expedient adopted to eliminate mud and make the earth roads more serviceable is to oil them. Briefly, the procedure is to spray from one-half to two-thirds of a gallon per square yard of a fluid fuel oil onto the well graded and consolidated earth road surface. The earth is generally a silt or clay loam. Over ten thousand miles of highways are maintained in this way by the use of over forty-five million gallons of oil annually. The oiled earth is made to serve the need till traffic grows to a volume warranting the building of pavement. Road oiling in Illinois has come into use through the efforts of county officials to meet their problems and has not been given much systematic study. The Engineering Experiment Station of the University of Illinois and the Highway Department of the State have given some attention to the work and have published their observations.[11]

[11]"The Oiling of Earth Roads." W. M. Wilson, Circular No. 11, Engineering Experiment Station, University of Illinois, 1924.
"Quality of Oil for Surface Oiling of Earth Roads and Streets." F. L. Sperry, American Society for Testing Materials. Part II, 1925, p. 376.

A somewhat different form of earth road oiling is practised by the counties in California. The soil on the road surface is loosened to a depth of from two to six inches and oil is mixed with it by the use of such implements as ploughs, discs and harrows. Asphaltic residual oil containing from 60% to 65% of 80 penetration asphalt is used in such quantity as to give the soil treated an oil content of 7% to 8%. The treated soil is smoothed out and compacted generally by the action of traffic, but sometimes by rolling. This form of treatment has been tried on all varieties of California soil Experience has shown that it is not a success with clay or alkali soils. Excellent results are obtained with gravelly, sandy and silty soils. Many of these oiled roads are serving under moderate traffic conditions very satisfactorily and at low maintenance costs. Their surfaces have the appearance of high class pavement and are about as comfortable as pavement to ride over.[12]

Earth Road Oiling Experiment Using Bituminous Sand Bitumen.

The progress gained in Illinois, California and elsewhere suggests the possibility of developing a suitable procedure for earth road oiling in Western Canada. The Scientific and Industrial Research Council of Alberta has made the start toward this objective in connection with its bituminous sand studies. Bitumen produced by its experimental bituminous sand separation plant was used in the treatment of a short stretch of earth road surface.[13] The road surface was loosened to depths varying from two to six inches in different sections, the hot bitumen was sprayed onto the loose earth in a number of applications to provide a bitumen content of about 10% and the earth and bitumen mixed together by discing. The bituminized earth was properly distributed with a grader and allowed to compact under traffic. A seal coat of bitumen and a sprinkling of sand or cinders was put on the surface as a final operation.

The experiment yielded the information sought. The section of road treated was in heavy clay soil. While it was realized that the chances of making a good piece of road would be much better in lighter soil, heavy clay is a prevalent condition in the province and is the one for which methods of improvement are most urgently needed. The clay roads leading out of Edmonton were the most convenient to work on, and it was considered that the results of a test of the stabilizing effect of the bitumen from the bituminous sands on clay soil would be as useful information as that to be gained under any other soil condition. The loosening of the surface of the hard clay road to the desired depth of finely pulverized soil was difficult to accomplish. It was equally difficult to mix the viscous bitumen into the loosened soil. The final mixture packed readily and gave a good surface. The stabilizing effect of the bitumen was very marked. Whereas an adjacent section of road treated in a similar way with asphaltic crude oil showed very little increase of resistance to turning to mud under the action of

12"Light Asphaltic Oil Road Surfaces." C. L. McKesson and W. N. Frickstad. Public Roads, September, 1927, p. 155.
13Fourth Annual Report of the Scientific and Industrial Research Council of Alberta, 1923, p. 68.
Sixth Annual Report of the Scientific and Industrial Research Council of Alberta, 1925, p. 55.

wet weather and traffic, the bituminized section retained a firm road bed. However, when the sprinkling of cinders disappeared, the surface of the bituminized clay became very greasy and slippery during wet weather. It got rough and then it was found that the treated clay was too hard and dry to restore to a smooth surface by grading. Apparently a satisfactory practical result cannot be obtained by simple treatment of clay roads with the bitumen from the bituminous sands. The marked tendency toward stabilization against wet conditions, however, suggests that lighter soil types might be satisfactorily treated. And in view of California experience, there is good reason to suppose that the treatment would be highly effective and practical under loose, sandy conditions.

Modified Form of Earth Road Oiling in Saskatchewan.

A modification of the oiling of earth roads consists in placing on the oiled surface a veneer of oiled sand or gravel. This method of construction has been used in North and South Carolina, Minnesota, and other States with good results.[14] During the season of 1928, the Province of Saskatchewan constructed 25 miles of road east and west from Regina in accordance with Minnesota practise. The very heavy gumbo surface was reconditioned and maintained to proper cross-section while traffic consolidated it. An application of ½ gallon per square yard of hot, asphaltic oil was applied and allowed to penetrate into the earth road bed. A second similar application was then applied and gravel was bladed over the surface from windrows along the shoulders of the road. The quantity of gravel used was 600 cubic yards per mile of 24 foot roadway. This would give an average depth of about 1½ inches of gravel. The second application of oil soaked up through the gravel covering, binding it together and waterproofing it. With adequate maintenance, this road should give the same satisfactory service as similar work in Minnesota is giving.

Maintenance of Gravel Roads by Oil Treatment.

Some form of oiled earth road may be evolved which will fit prairie conditions satisfactorily from the standpoint both of serviceability and economy. But in the meantime the highway departments are meeting imperative demands for improved road surfaces by the well-tried method of gravelling. Alberta, for instance, has built about 600 miles of gravel road and will continue the work on its 2,500 miles of main highways. In spite of the fact that gravel is hard to find and must generally be hauled by train for considerable distances, this form of construction appears to be the best first step on the prairies just as experience has proved it to be elsewhere.

The gravel road has the virtue of comparatively low initial cost; but it has disadvantages. The principal one is that the gravel wears out, especially under the action of automobiles, and disappears from the road surface. A number of Western States that have investigated this point have estimated that from two to five hundred vehicles a day using a road will wear off from one to one and a half

[14]"Surface Treatment of Earth Roads by the Hot Application Method." N. S. Anderson. Contract Record, December 22, 1926, p. 1218.
"Bituminous Treatment of Earth and Gravel Roads." H. G. Nicholson. The Canadian Engineer. October 9, 1928, p. 96E.

inches of gravel per year. The constant loss of material causes dust, makes the surface rough, and represents a large loss of investment in gravel.

Some Types of Gravel Road Treatment with Oil.

Treatment of the surface with some form of oil is the general procedure that has been adopted to overcome these disadvantages. Such treatment increases the cost of the gravel road, but improves its quality. It stops, to a large extent, the loss of material from the surface, and in proportion to the degree to which this is accomplished, the problem of dust, roughness and loss of investment in gravel are overcome. The cost of treatment is more than made up by savings in maintenance and replacement of material. Further, such treatment of the relatively low-priced gravel road makes it capable of giving adequate road facilities to larger volumes of traffic.

The simplest form of treatment consists of spraying the gravel road surface with a light, fluid oil. Before oiling, the surface is made smooth and free from dust. About one-third of a gallon of oil per square yard of surface is applied by a distributor. The oil soaks into the gravel and, as long as the effect lasts, the oil prevents dust from flying and helps to keep the surface smooth. It supplies little actual bonding of mineral particles. This dust-laying operation must be done at least once a year.

Heavier oils have to be used to cement together the gravel particles of the road surface as well as to lay the dust, and many varieties of asphaltic road oils and coal tar preparations have come into use for this purpose. These oils are applied in much the same way as are the light oils used for dust-laying; but as they do not soak into the gravel nearly so rapidly, a layer of fresh gravel is spread over the oiled surface. The final result is a road surface with a mat of gravel firmly bonded by the bituminous material. This mat resists the action of weather and traffic and so long as it persists intact it gives a dust-free road with excellent riding qualities. By vigilant maintenance, this form of treatment will last for three years or more, if the traffic on it is not too large.

The preservation of a thin bituminous surface mat becomes a difficult matter if traffic grows to considerable volume. Increase in the thickness of the treatment is being accomplished by loosening the surface of the gravel road to the depth to which treatment is desired, say two inches, and mixing in a suitable asphaltic oil or tar. The oil is applied from a distributor, and oil and loose gravel are mixed together by being rolled about on the road surface by a blade grader. When mixing is complete, the oiled gravel is spread out to proper shape and allowed to pack under traffic.[15]

Inauguration of Gravel Road Oiling in Western Canada.

The problem of maintenance has appeared in connection with gravel roads in Western Canada and oil treatment has been turned to as the solution. Three years ago, the Alberta highways marked for gravelling were carrying a traffic which probably never ex-

[15]Cf. "Light Asphaltic Oil Road Surfaces," C. L. McKesson and W. N. Frickstad, Public Roads, Sept., 1927, p. 125, for an excellent discussion of the gravel road maintenance problem and the various methods used in the western states for oil surface treatment.

ceeded two hundred vehicles per day. But with the improved surface, traffic has been about doubling yearly till now it exceeds one thousand vehicles per day on some sections. Such a volume of traffic combined with prairie conditions of dryness and persistent winds has resulted in large losses of surfacing material. These losses are particularly serious because of the scarcity of gravel and the cost of moving it long distances. So it has come about that almost simultaneously with the inauguration of gravel road construction, maintenance by oiling has had to be adopted. In all probability, gravelling and oil treatment will proceed practically together in future work.

A number of miles of Alberta gravel roads were oil treated during the 1928 season. The oil for this work was purchased from the Imperial Oil Company refinery at Calgary. A number of grades of road oil were tried and sections were treated in somewhat different ways. In general, however, the gravel road bed was reconditioned and consolidated, an application of oil was sprayed onto the surface and allowed to penetrate, a second application was applied and covered over with fresh gravel. A surface layer of gravel firmly bound together by an oil with good cementing properties was aimed for.

Suitability of Bitumen from Bituminous Sands as a Road Oil.

No test of the suitability of the bitumen from the bituminous sands for gravel road treatment has been made. There is little doubt but that it would prove satisfactory and useful. It is a native liquid asphalt with excellent cementing properties. Its consistency is comparable to that of 70% to 80% liquid asphalt used in road construction work. It would have to be heated to 200°F. for application by spraying and a mixing operation would be required to distribute it through gravel. With appropriate procedure for handling the bitumen and getting it into the surface, a serviceable road should result.

Cost Factors in Marketing Bitumen as a Road Oil.

From the standpoint of bituminous sand development, the question is whether the coming demand for road oil in Western Canada will provide a basis upon which a bituminous sand industry could be established. In other words, can the bitumen be separated and marketed profitably at a price below that of refinery road oils and will the road oil market become sufficiently large to provide enough business to support an industry?

The cost of producing separated bitumen from the bituminous sands, according to available data, is estimated to be approximately \$5.65 per ton.[16] This figure includes mining of the sand and separation of the oil. Freight to Edmonton would amount to about \$6.30 per ton if it were handled on the same basis as crude oil between Coutts, Alberta, and Calgary.[17] If handled on the same basis as road oil is distributed in tank-car lots around the province, the

16Part II, p. 29.

17Crude oil is hauled in 15 tank-car train lots from Coutts to Calgary, a distance of 142 miles, for 15c per 100 pounds. The distance between the bituminous sand deposits at Waterways and Edmonton is about 300 miles.

freight would amount to about $11.70 per ton.[18] The cost of the bitumen at Edmonton would consequently be $11.95 or $17.35 per ton depending on which freight rate would be charged. These costs are the equivalent of 6 cents and 8¾ cents per gallon respectively.

The Imperial Oil Co. price to the province in 1928 for road oil was 7 cents per gallon f.o.b. Calgary. Thus, the best that could be hoped for the bitumen would be to place it at Edmonton at the same price as road oil in Calgary. It could then compete with Calgary oil in the northern half of the territory between Calgary and Edmonton and in the Peace River country in the north of the province. The refinery at Regina would prevent the bitumen from entering Saskatchewan.

The Road Oil Market.

There are about 1500 miles of main highway in the part of the province north of a line midway between Calgary and Edmonton. The provincial government carries the entire responsibility for construction and maintenance of these roads. It is responding to persistent demand for better roads by building up the main highways to a good standard and gravelling them as rapidly as possible. It is not at all improbable that very soon such work will be proceeding on the northern part of the system just referred to at the rate of 300 miles per year. And as it has been pointed out that conditions in Alberta make it necessary to follow up gravel construction with oil treatment almost immediately, it is equally probable that road oiling will proceed at an equal rate. The oil treatments would continue till the gravelled roads were superseded by some higher form of construction.

Assuming that the application of oil for new work and maintenance would be ½ gallon per square yard, a mile of 20 foot roadway would require 6000 gallons of oil. The 300 miles of oiling per year would provide a market for 1,800,000 gallons or 9,000 tons of oil. It would take 60,000 tons of bituminous sand to yield this much bitumen. The separation of this quantity of sand during a 200 day season would require a 300 tons per day plant.

The estimate of $5.65 per ton has been given as the cost of producing separated bitumen. It should be noted, however, that this estimate is for operations on the scale of 1000 tons of bituminous sand per day for a season of 200 days. On operations of the scale of 300 tons per day, mining costs would be doubled or trebled, separation unit costs would be higher and the possibility of placing the bitumen at Edmonton at a price equal to road oil at Calgary would disappear entirely.

No account has been taken of the consumption of road oil for treating earth roads or for work other than that on the main highway system. Neither of these uses will result in an appreciable demand for oil for some years to come. No system of earth road oiling has been evolved and none is being sought. Gravelling has been definitely adopted as the method to be followed in road improvements. As for work other than that on main highways, the municipalities are showing no inclination to undertake road work of a more advanced sort than earth road grading.

18Road oil is hauled in tank-car lots from Calgary to Edmonton, a distance of 200 miles, for 39c per 100 pounds.

CHAPTER IV.

ASPHALT EMULSIONS.

The marketing of the bitumen from the bituminous sands as an *asphalt emulsion* should be considered. The use of such emulsions in construction work is growing rapidly and plants for their manufacture are being established in all parts of the country.[19] The asphalt content of the bituminous sands emulsifies very readily. And the preparation of it as an emulsion would avoid the difficulty and expense of dehydration of separated bitumen. At first glance emulsion manufacture appears to fit the bituminous sand development problem nicely.

Uses and Advantages of Asphalt Emulsion.

During recent years, asphalt emulsions have come into favor for bituminous road construction. They were developed in Europe to meet the need for a bituminous material that could be used in damp weather and with damp materials. Dry oils and asphalts will not adhere to or spread on wet stone surfaces. An asphalt emulsion, on the other hand, being a fine suspension of asphalt in water, will spread on a damp or wet surface even more readily than on a dry one. The water in the emulsion as well as on the stone eventually evaporates leaving the stone surface with an asphalt coating just as would have been the case if dry stone and dry asphalt had been used. The emulsion has the further important feature that it is a fluid material at ordinary temperatures no matter how viscous or hard the asphalt that has been emulsified. Consequently an asphalt that would have to be heated to a high temperature to make it fluid and which could be spread on stone surfaces only if the stone were also heated, can be emulsified and in this form spread over stone at out-of-doors temperatures. Consequently, asphalt emulsions eliminate the necessity of two troublesome construction conditions, namely, dry materials and the use of heating operations. These advantages have appealed to European road builders with the result that increasingly large quantities of asphalt emulsion are being used in England, France, Germany and other countries.[20] The success with emulsions in Europe lead to their introduction in America. They are now being manufactured in all parts of this continent and are rapidly gaining recognition as a convenient and satisfactory road construction material.

Asphalt emulsions are proving useful for other purposes than for road construction. One of the most important of these is the

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[19]The Canadian Engineer, Oct. 9, 1928, p. 242. There are five brands of asphalt emulsions being manufactured in Canada at the present time, some in several plants. They are sold under the names of Colas, Bitumuls, Colfix, Coldphalt and Coldprovia. A considerable amount of demonstrational road construction was done by the different manufacturers during 1928.

[20]"Impressions on Road Building in Europe," by C. L. McKesson, formerly Materials and Research Engineer, Division of Highways, Department of Public Works, Sacramento, California. The impressions were presented in a paper before a meeting of the Western Association of State Highway Officials at Los Angeles, March 11, 1928, and later published in pamphlet form.

waterproofing of concrete structures.[21] An asphalt of sufficient hardness to be suitable as a waterproof facing on concrete must be heated before applying, and if the concrete is green or otherwise damp, the application will not adhere properly. The asphalt emulsion, on the other hand, can be applied cold like paint, any thickness of asphalt coating can be made, and the coating adheres perfectly whether the concrete is dry or damp. Increasing quantities of emulsion are being used in this way.

Road Construction with Asphalt Emulsion.

A large amount of bituminous surface treatment of roads is being done in Europe by means of asphalt emulsions. Old macadam roads to be surface treated are very thoroughly cleaned. All dirt and fine material are removed by washing with water, sweeping with hand or power brooms, air jets and such means till the stone of the macadam is brought out in strong relief. Asphalt emulsion is applied at the rate of about ½ gallon per square yard. The surface is then covered with stone chips freed from dust or other fine material. The chips are evenly distributed by suitable means and a final rolling may be given. The emulsion remains fluid long enough to thoroughly coat all the chips and when the water finally leaves the road, the chips are bound together with asphalt.

European engineers also use asphalt emulsion for placing bituminous penetration macadam on old stone roads. Crushed stone of 1¼ to 2 inch size is placed to the desired depth on the road surface and rolled into place. A small quantity of stone chips is put over the broken stone to prevent the emulsion from running into the bed of stone too quickly. About 1½ gallons of emulsion per square yard are then applied, more stone chips are spread and swept into place until the voids in the surface of the large stone are filled. The road is rolled during this operation. Finally, a seal coat of about ½ gallon of emulsion per square yard covered with stone chips is given to the road surface and rolled.[22]

Preparation of pre-mixed road aggregate similar to that used for bituminous concrete is being done to some extent with asphalt emulsion. Some emulsion manufacturers advance this use in their advertising. During the 1928 season, a decking for a bridge on the road between Calgary and Banff, Alberta, was laid with an aggregate of crushed gravel and Colfix mixed together in a concrete mixer.

Gravel Road Treatment with Emulsion of the Bitumen from Bituminous Sands.

The Scientific and Industrial Research Council of Alberta made a practical test of the suitability of emulsion of the bitumen separated from the bituminous sands for gravel road treatment.[23] It

21Eighth Annual Report of the Scientific and Industrial Research Council of Alberta, 1927, p. 13. While studying the technique of emulsifying the bitumen of the bituminous sands for a practical road experiment, a ton of asphalt flux bought from the Imperial Oil Company was emulsified. The City of Edmonton used the emulsion in an experimental way for waterproofing part of the concrete work of a subway structure. The emulsion was easily applied and gave a tenaciously adhering asphalt coating.

22cf. "Impressions on Road Building in Europe", by C. L. McKesson, for detailed descriptions of road projects in various countries of Europe. Much of the pamphlet is devoted to construction using asphalt emulsions.

23Eighth Annual Report of the Scientific and Industrial Research Council of Alberta, 1927, p. 42.

will be noted that the brief description of European practice indicates that asphalt emulsion is always used with clean broken stone. If emulsions are used in Western Canada during the present stage of road construction, it must be for treatment of ordinary pit-run gravel. A test of their suitability for this purpose was considered of importance both in regard to road problems and to bituminous sand development.

Approximately fifty barrels of bitumen, left over from the 1925 bituminous sand separation operations[24] were used for the road experiment. The bitumen was emulsified without difficulty in a small colloid mill using rosin soap and starch as stabilizing reagents. The emulsion was then mixed with pit-run gravel in a concrete mixer. The gravel-emulsion mixture was hauled by truck from a stock pile to a short stretch of regraded earth road and placed in a windrow down the centre of it. A power grader spread it out to an average depth of four inches over the road and kept the surface smooth while traffic compacted it.

Discussion of the Results of the Emulsion Experiment.

A number of the features of the experiment are worthy of note. The gravel-emulsion mixture, even after being in storage for several weeks, handled much the same as ordinary damp gravel. It was loaded into the trucks with a steam grab-bucket, dumped in a windrow through the end-gates of the trucks as they moved forward and spread by a grader blade in just the same way as gravel is manipulated in ordinary gravel road construction. The mixture consolidated at once under traffic. By the time the grader had the material spread, the vehicles passing over it rode up on the surface. Several days elapsed, however, before the surface set so that it was difficult to work with the grader.

Too little emulsion was mixed with the gravel in the experiment. At the time, the engineers of the provincial Public Works Department were of the opinion that maintenance of road surfaces would have to be confined to blade grader work. Consequently a gravel mixture with enough bitumen to make it pack but not enough to make a too firmly bonded surface for a grader to cut was aimed for. Preliminary tests indicated a bitumen content of three per cent. to be what was wanted. Actually, two and three-quarters per cent. was secured. The mixture packed well, but had too open a texture to prevent water from entering the surface. The bitumen bond was not enough to prevent traffic from loosening the surface particles which at once lost their thin bitumen coating and were ground up. And even the small quantity of bitumen used gave too strong a bond to the body of the road bed to allow of effective grader maintenance. If a seal coat of emulsion had been placed over the surface or if an inch or so of gravel mixture containing five or six per cent. of emulsified bitumen had been spread as a final operation, the result would have been much better from the standpoint of a practical road.

The mixing of the emulsion with the gravel revealed an interesting problem which probably explains why in asphalt road building practice such great care is taken to clean the road surface thor-

[24]cf. Part II, p. 24.

oughly before application of emulsion and why only clean stone or chips are used in conjunction with it. On mixing the gravel and emulsion together, the emulsion promptly "broke" into water and wet bitumen. The result was that the bitumen was distributed through the gravel in small masses sticking the fine particles together instead of being evenly distributed over all surfaces. Pebbles and larger sand grains had no bitumen on them at all. They were merely wet with water. This point was further examined in the laboratory and it was found that while emulsion would spread readily over coarse material before breaking, trouble appeared when the size of the particles was reduced to 50 mesh or smaller. A number of commercial emulsions were tried and they behaved in a similar manner to the emulsion made from the bitumen of the bituminous sands. With any size of particles, the emulsion will break eventually, but when the particles are reduced to 50 mesh, the time before breaking is not long enough to allow of proper mixing and distribution of emulsion on all surfaces.

In spite of the breaking difficulty, the gravel-emulsion mixture used in the road experiment gave good results. The mixture packed well. But it seems obvious that some means must be evolved of mixing emulsion and gravel so as to get a uniform bitumen distribution before emulsions can be used with gravel roads to best advantage. This may be accomplished by making emulsions which will not break so quickly in presence of fine material.[25] Or the desired result may be secured by better adapted methods of mixing. The spraying of emulsion onto a cascade of gravel is worth trying. This expedient would reduce the mixing time to zero.

Asphalt emulsions in conjunction with gravel road work offer interesting possibilities. They provide a simple way of introducing into gravel a bitumen with far better bonding properties than those possessed by the road oils in common use. The latter have their asphalt content thinned down by admixture with light oil of some sort so that the road oil will be fluid enough to handle and mix with gravel. The result is that the cementing ability of the asphalt is much decreased. An asphalt of any consistency may be made fluid by emulsification and introduced into gravel without use of heat. The presence of the water keeps the gravel mixture in a condition in which it is easily handled and spread. Once in place in a comparatively thin layer on the road, the water soon disappears leaving the asphalt to exert its full bonding power. Further, emulsions provide a way of introducing any desired quantity of asphalt into the road aggregate. A few per cent. of asphalt will make a gravel pack solidly at once even though it will not give it a tight wearing surface. This effect should be useful under the conditions in Western Canada where gravel is not only expensive to place on roads, but is also scarce and should be conserved. When gravel is spread loose on a road a large amount is lost before the remainder consolidates under traffic into a firm bed. The cost of mixing two or three per cent. of asphalt in emulsified form into the gravel before it is placed on the road and sealing the surface when it has packed and set on the road with an application of emulsion

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[25]The Bitumuls Corporation of San Francisco, Cal., is now advertising an emulsion with retarded break-down for use with gravel.

probably would not be much greater than the cost of the gravel that would otherwise be lost and would be well justified from the standpoint of gravel conservation.

Emulsification would be a neat way for adapting the bitumen of the bituminous sand to the sort of road work that is coming to the fore in Alberta, along with other parts of the province. Anyone who has worked with this material realizes that it would be an excellent binder for gravel. But it is too viscous to handle easily like road oils. This difficulty disappears if the bitumen is prepared as emulsion and its good body and cementitiousness becomes an advantage.

Emulsion Manufacture as a Basis for a Bituminous Sand Industry.

From the standpoint of bituminous sand development, manufacture of asphalt emulsion is faced with similar economic conditions as face manufacture of road oil. The quantity of emulsion that could be used for road construction in Alberta must be expressed in large figures, but the quantity of bitumen which should be produced to make a basis for a satisfactory bituminous sand mining and separation industry is still larger. However, preparation of bitumen as emulsion has at least one advantage over its preparation as a road oil which may have important possibilities. Whereas the marketing area for bitumen as a road oil would be restricted because of competitive oils, the bitumen as emulsion might claim a much wider range of sale. Asphalt is not being produced in Western Canada, and if asphalt emulsions come into extensive use, the bituminous sands would be the natural source of asphalt for their manufacture throughout the whole of the prairie provinces. Under such circumstances there would be opportunity to develop the bituminous sands on a satisfactorily large scale.

CHAPTER V.

MANUFACTURE OF GASOLINE FROM BITUMINOUS SANDS.

The use of bituminous sands as a crude material for the petroleum industry has been given little consideration. Robert Bell, in his report to the Geological Survey of Canada in 1882[26] expressed the opinion that the bituminous sands would have value, eventually, because of their oil content. He commented that it had been reported to him that the bitumen would yield a good grade of lubricating oil. A number of schemes have been proposed and attempts have been made to produce a crude oil from the bituminous sands by destructive distillation.[27] S. C. Ells has expressed the view that the bituminous sands should be regarded as a potential source of liquid hydrocarbons, and has discussed the possibility of gasoline manufacture.[28] However, he considered such developments to be a matter for the indefinite future. Since the bituminous sands have no gasoline content and since gasoline is the outstanding remunerative product of the petroleum industry, there has seemed little reason for giving much thought to the possibilities of refining petroleum products from the bituminous sands.

However, rapid and revolutionary developments in oil refining technology have been taking place in recent years. The result has been that the status of such oils as the bitumen content of the bituminous sands for gasoline manufacture has been completely changed. While refining depended on straight distillation, oils of this sort were worthless for this purpose. But with the new methods of cracking, these same oils can be broken up by heat and pressure into surprisingly large yields of motor fuel. Over one-third of the gasoline of today is produced by cracking from oils which contain no gasoline as such. Modern refineries fractionate crude oil by distillation into gasoline and other products and then put such of these other products through their cracking plants as it is profitable to do. There is no great technical difficulty about using any oil or bitumen for gasoline manufacture. Whether it is practical to use them is almost entirely a question of economics.

Oil Refining Conditions in Western Canada.

The conditions for oil refining in the Canadian West are somewhat unusual and may be such as to make the manufacture of gasoline from the bituminous sands feasible, at least for the Alberta market. Under ordinary circumstances on this continent, an oil such as the bitumen of the bituminous sands is not used as charging stock for cracking plants for the reason that better oils for the purpose are abundantly available at low cost. Western Canada,

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[26] "Report on Part of the Basin of the Athabaska River, North-West Territories." Geological Survey of Canada, 1882-84, part CC.

[27] Part I, p. 10.

[28] "Bituminous Sands of Northern Alberta." S. C. Ells, Report No. 632, Mines Branch, Department of Mines, Ottawa, 1926, p. 101.

however, has no adequate petroleum fields of its own.[29] It is an inland territory far removed from petroleum supplies moving cheaply over the oceans. And it is also separated by a long land haul from the nearest American oil fields. The bituminous sand deposits are comparatively close to a part of Alberta which consumes large and rapidly increasing quantities of gasoline. These conditions may give the bituminous sands an advantage over other available crude material in a sufficiently large market to support an industry. The situation is worth examining.

The location of the oil fields of North America are shown on the outline map of Fig. 1. The one nearest to the provinces of Western Canada is the Rocky Mountain field in Montana, Wyoming and Colorado. The daily production of this field is about 80,000 barrels, of which Wyoming contributes about 60,000 barrels. Montana produces a little more and Colorado a little less than 10,000 barrels per day each. The Rocky Mountain field is the least productive of all the American fields. Its market covers a wide area in the northwestern states and provinces of the United States and Canada.

TABLE III.—APPROXIMATE DAILY PRODUCTION OF THE OIL FIELDS OF NORTH AMERICA.

	Fields.	Barrels per day.
1.	Fort Norman	Not producing.
2.	Bituminous Sands	Not producing.
3.	Turner Valley	1,000
4.	Rocky Mountain	80,000
5.	Eastern	112,000
6.	California	625,000
7.	Mid-Continent	1,500,000
8.	Gulf Coast	125,000
9.	Mexican	125,000

Comparative Cost and Value of Bitumen as a Crude Oil.

The crude oil from the Rocky Mountain field sells at a low price, but freight charges on it into Canada make it expensive. The lowest grade of Wyoming crude (29-31° Bé) sells for about one dollar a barrel. The distance from Caspar, Wyoming, an important petroleum shipping point, to Coutts the port of entry into Alberta, is about 525 miles. It is 342 miles from Coutts to Edmonton, Alberta. Crude oil is hauled 142 miles from Coutts to Calgary, Alberta, in tank-car train lots for 15 cents per 100 pounds.[30] Assuming the same rate basis for the 867 miles from Caspar to Edmonton, the freight charge for this haul would be 92 cents per 100 pounds. This would amount to $2.75 on a barrel of oil of 300 pounds. The total cost of the Wyoming crude at Edmonton would thus be approximately $3.75 per barrel.

The cost of producing separated bitumen from the bituminous sands has been estimated to be $5.65 per ton[31] or $1.00 per barrel of 350 pounds. The distance from Waterways to Edmonton is 300

[29] The Turner Valley oil and gas field in Alberta produced during November, 1928, an average of 585 barrels per day of 44° to 52° Be crude oil and 740 barrels per day crude naphtha stripped from the natural gas flows. The consumption of gasoline in Alberta during 1928 averaged 3,200 barrels per day.

[30] Canadian Pacific Railway Freight Tariff No. W. 5777, p. 24.

[31] Part II, p. 31.

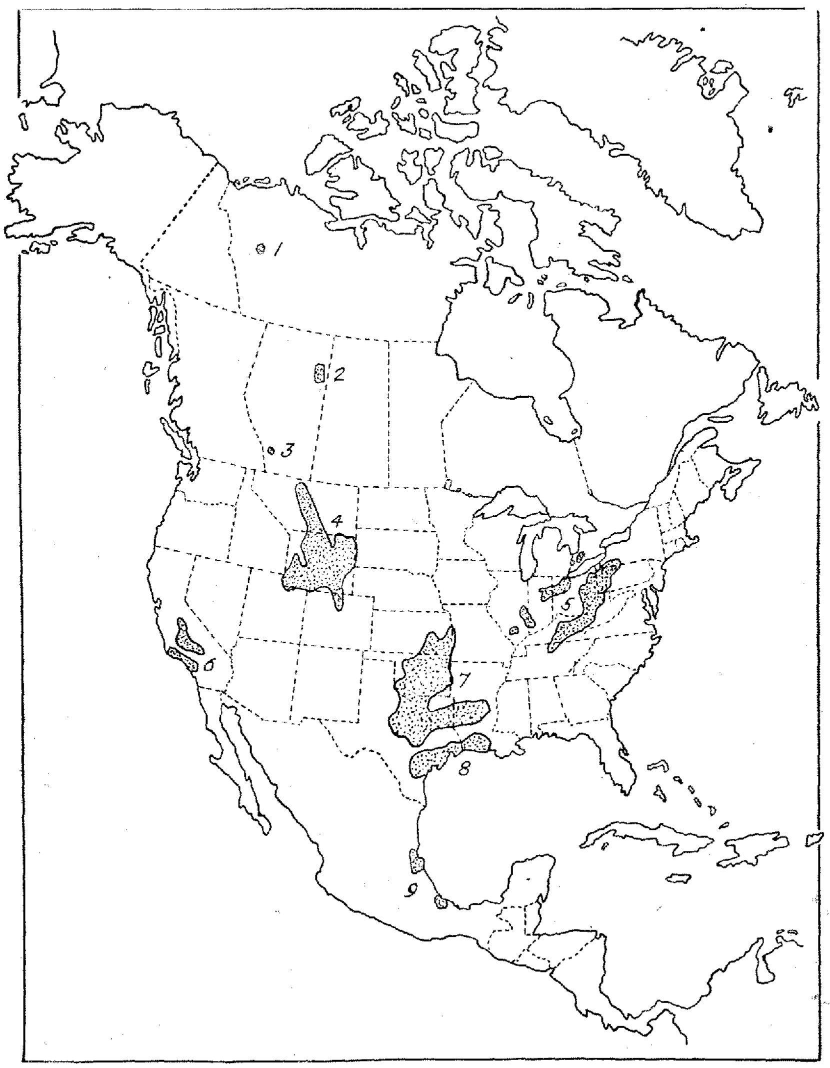

Figure 1.—Sketch Map of North America showing the Locations of the Oil Fields (cf. Table III).

miles. The freight per 100 pounds, using the same basis as applies between Coutts and Calgary, would be 31½ cents and on a barrel of 350 pounds it would amount to $1.10. This would bring the cost of a barrel of seperated bitumen at Edmonton to $2.10, or a little more than one-half the cost of the Wyoming crude.

Is low grade oil from Wyoming worth twice as much as bitumen from the bituminous sands as a crude for gasoline manufacture? This is a question for those familiar with oil refinery costs to answer. It is no doubt a many-sided problem. Cracking tests have been made on the bitumen. The Universal Oil Products Company, owners of the Dubbs Process, reported that their tests gave a yield of 45% gasoline when the bitumen was cracked down to gasoline, coke and fixed gases.[32] In their own published report, the yield of finished gasoline is given as 36%.[33] Data supplied by the Dominion Bureau of Statistics indicates that the refineries on the prairies are obtaining a yield of a little less than 50% of gasoline from the crude oil they import from the United States.[34] This will be mainly Wyoming crude and probably not the lowest grade of it. Using yields of gasoline as the basis of comparison, if Wyoming crude costing $3.80 per barrel yields 50% gasoline, bitumen yielding 36% gasoline should be worth $2.75 per barrel. Such comparison is no doubt inadequate. But it at least indicates that it is possible that a proper comparison would not be unfavorable to the bitumen.

Factors Affecting Use of Bitumen.

Any advantage that the bitumen may have under present conditions will be increased proportionately to increases that may take place in the cost of American crude oil. For a number of years, petroleum prices have been forced to low levels by over-production. Decreasing profits and a too rapid, uneconomical consumption of petroleum resources have aroused both the oil industry and the American federal and state governments to serious efforts to curtail crude oil production in the United States to an amount in keeping with market requirements. In all probability these efforts will succeed, eventually, in attaining their objective. The result will be beneficial both to the industry and to the nation at large. But it will have the further result of raising crude oil prices in the American oil fields and consequently their cost at Canadian refineries. It may also affect the quality and quantity of petroleum from the Rocky Mountain field available for export to the prairie provinces.

The best solution for the question of oil supplies for Western Canada would be, of course, the discovery of oil fields in this territory which would be profitable to develop and which would

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[32]Part II, p. 33. c. also "Investigations of Fuels and Fuel Testing." Report No. 689, Mines Branch, Department of Mines, 1926, p. 129, for results of tests by the Cross cracking process on the bitumen. A yield of 40% gasoline is reported.

[63]"The Cracking of Bitumen from Canadian Alberta Tar Sands." Gustav Egloff and Jacque C. Morrell, 1926. This report has been printed and distributed by the Universal Oil Products Co.

[34]**Crude Oil used in Petroleum Refineries in Man., Sask., and Alberta.**

	Imported.		Canadian.	
1925	75,537,045 Imp. gals.	$6,834,051	5,244,967 Imp. gals.	$ 735,454
1926	125,987,971 Imp. gals.	9,741,143	3,843,296 Imp. gals.	602,744
1927	114,345,194 Imp. gals.	8,309,748	9,038,822 Imp. gals.	1,247,464

Gasoline produced in Manitoba, Saskatchewan and Alberta.

1925	41,577,328 Imp. gals.	$ 8,297,629
1926	62,080,461 Imp. gals.	11,609,775
1927	62,280,442 Imp. gals.	10,125,655

yield adequate quantities of petroleum. Whether this solution will be accomplished is still doubtful. The distribution of the known oil fields of North America shown in Figure 2 suggests that the prolific fields such as the Mid-continent, Californian, Gulf Coast and Mexican fields are located far to the south, and that resources of oil diminish northward. The northerly fields in the Eastern States and in Wyoming, Colorado and Montana produce comparatively small quantities of petroleum. Neither of these latter have been found to continue into Canada to any great extent. A considerable amount of drilling has been done in the prairie provinces. That done in Alberta has met with varying degrees of success. Natural gas in large quantities has been struck in a number of localities.[35] On the plains, heavy asphaltic oil of from 15° to 18° Baumé gravity has been found near Skiff in south-eastern Alberta, near Wainwright, 125 miles south-east of Edmonton, and in the Peace River district. Light crude oil and heavy gas flows carrying naptha have been found in Turner Valley, about 25 miles south-west of Calgary.

The developments in Turner Valley are by far the most significant of all efforts so far in the search for oil in Western Canada. There has been great activity in this field during the past two years and scores of wells have been drilled or are now in process of drilling. During 1927, 290,270 barrels of crude naphtha (65° to 73° Bé gravity) were separated from the heavy gas production and 38,808 barrels of light crude oil (44° to 55° Bé gravity) were produced. This is the equivalent of a daily production of 800 barrels of naphtha and 105 barrels of crude oil. During November, 1928, the yield of naphtha was 740 barrels per day, while that for light crude had increased to 585 barrels per day. Five wells were reported for the month as producing naphtha, the largest yielding 530 barrels per day, and the average yield being 150 barrels per day. Sixteen wells were reported as producing crude oil, the largest yielding 200 barrels per day, and the average yield being 35 barrels per day. The productive wells are distributed over an area extending six miles north and south and two miles wide.[36]

The Turner Valley activity may be the start in the finding and developing of Canadian oilfields which will take care of the needs of the prairie territory in a way which will leave no chance for successful competition by bituminous sand development. At the present, this field is producing the equivalent of about one-quarter of the gasoline being used in Alberta. Production will probably increase. Other favorable structures in the foothills are being tested and some of these may prove as productive as the Turner Valley structure or even more productive. Bituminous sand development would not be confronted with the uncertainty that attends the search for oil fields. The bituminous deposit is in plain sight and is of enormous extent. But full consideration must be given to the possibility that important discoveries of petroleum

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[35]cf. Seventh Annual Report of the Scientific and Industrial Research Council of Alberta, Edmonton, Alberta, 1927, p. 34. J. A. Allan lists eleven gas fields with a total capacity of 480,000,000 cu. ft. per day. Large additions have been made since 1927.

[36]cf. The Canadian Mining and Metallurgical Bulletin, Petroleum News Section from July, 1926, to date, for information about the progress in Turner Valley development as well as that at other locations in Alberta.

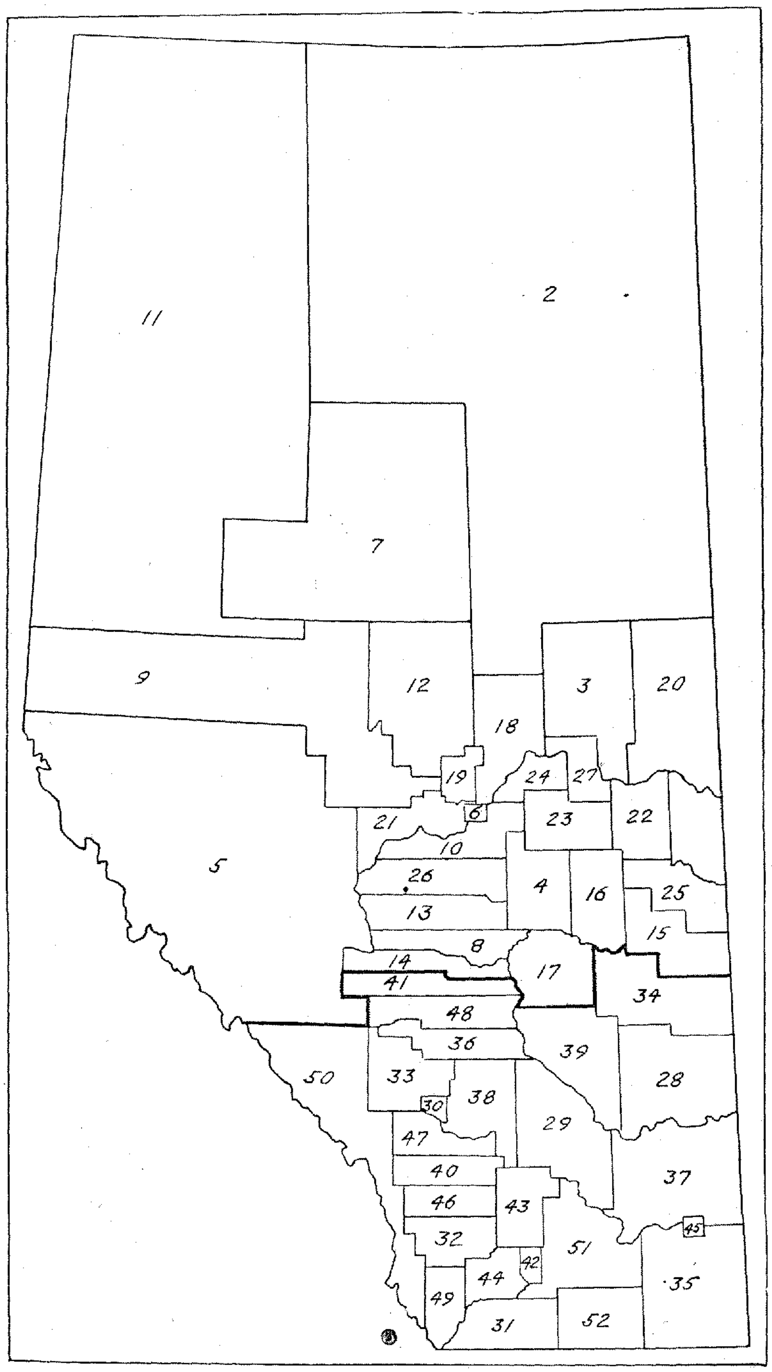


Figure 2.—Map of the Province of Alberta showing Its Division into Provincial Electoral Districts (cf. Table IV).

pools might remove any favorable opportunity that may exist now or in the future for a profitable bituminous sand industry.

Market for Gasoline from the Bituminous Sands.

If it is granted that conditions are such now, or will become such in the near future, as to make manufacture of gasoline from bituminous sand bitumen feasible, the question then comes whether the gasoline market would be sufficiently large to support an industry. The consumption of gasoline in Alberta for driving motor vehicles is revealed by returns from the tax on gasoline. It is shown in Table V. It is of interest to calculate what quantity of bituminous sand would have been required to supply Alberta with its 1928 requirement of gasoline. Assuming sand containing 15% of bitumen by weight, complete separation of bitumen and a 36% conversion of it into gasoline, the quantity required would

TABLE IV.—DISTRIBUTION OF MOTOR VEHICLES THROUGHOUT THE ELECTORAL DISTRICTS OF ALBERTA FOR THE YEARS 1922 TO 1928.

Northern Districts.	1922	1923	1924	1925	1926	1927	1928
1—Alexandra	386	395	417	555	765	1,022	1,267
2—Athabaska	51	57	54	71	117	140	158
3—Beaver River	63	70	78	106	149	208	244
4—Camrose	1,500	1,383	1,630	1,856	1,267	2,746	2,951
5—Edson	71	132	238	230	285	361	418
6—Edmonton	5,363	6,019	6,575	6,874	7,589	8,549	10,350
7—Grouard	9	22	30	55	103	159	219
8—Lacombe	691	791	886	989	1,079	1,282	1,503
9—Lac Ste. Anne	80	143	205	240	327	401	477
10—Leduc	483	458	480	701	889	1,035	1,222
11—Peace River	474	439	495	573	813	1,294	1,733
12—Pembina	212	275	341	473	691	785	923
13—Ponoka	480	513	540	612	693	769	914
14—Red Deer	662	753	841	875	1,074	1,240	1,617
15—Ribstone	734	698	647	838	1,073	1,378	1,705
16—Sedgewick	923	948	1,063	1,122	1,523	1,698	2,060
17—Stettler	1,194	1,014	1,214	1,320	1,650	1,930	2,080
18—Sturgeon	340	335	364	522	650	694	835
19—St. Albert	367	299	390	452	616	666	794
20—St. Paul	155	184	192	226	299	380	451
21—Stony Plain	286	292	333	417	576	590	702
22—Vermilion	503	439	499	590	685	808	977
23—Vegreville	887	881	1,050	1,312	1,653	1,836	2,170
24—Victoria	504	552	592	715	827	917	1,045
25—Wainwright	523	525	660	711	891	1,173	1,353
26—Wetaskiwin	640	563	658	730	949	1,043	1,251
27—Whitford	183	171	213	274	372	404	536
Total	17,764	18,351	20,685	23,439	28,605	33,508	39,955

Southern Districts.							
28—Acadia	625	547	699	657	831	888	1,264
29—Bow Valley	1,003	1,155	1,372	1,546	1,746	1,961	2,533
30—Calgary	6,075	6,446	7,210	7,836	9,828	10,105	12,138
31—Cardston	438	485	509	740	850	953	970
32—Claresholm	320	502	575	695	823	959	859
33—Cochrane	557	511	556	721	818	844	899
34—Coronation	747	619	822	816	1,232	1,499	1,716
35—Cypress	414	471	558	506	603	614	1,025
36—Didsbury	1,031	976	1,196	1,433	1,808	2,108	2,623
37—Empress	352	329	464	375	386	469	816
38—Gleichen	1,269	1,384	1,657	1,850	2,261	2,291	2,682
39—Hand Hills	1,151	1,002	1,333	1,299	1,684	1,858	2,408
40—High River	555	637	760	899	1,096	1,199	1,396
41—Innisfail	503	510	560	661	847	1,027	1,123
42—Lethbridge	1,254	1,504	1,394	1,493	1,615	1,755	2,220
43—Little Bow	917	954	1,147	1,280	1,523	1,701	2,364
44—Macleod	282	289	353	404	502	548	640
45—Medicine Hat	800	1,009	1,195	1,016	1,113	1,156	1,496
46—Nanton	357	417	505	597	722	816	872
47—Okotoks	315	334	353	428	594	667	760
48—Olds	621	544	692	771	1,003	1,177	1,321
49—Pincher Creek	297	351	364	456	507	528	604
50—Rocky Mountain.	771	969	990	1,039	1,025	1,203	1,553
57—Taber	943	1,171	1,272	1,229	1,438	1,672	2,266
52—Warner	385	440	504	571	653	693	976
Total	21,982	23,556	27,040	29,318	35,508	38,691	47,524
Grand Total	39,746	41,907	47,725	52,757	64,113	72,199	87,479
% of Cars in Northern Districts	45%	44%	43.5%	44.5%	44.5%	46.5%	45.7%

TABLE V.—GASOLINE USED BY MOTOR VEHICLES IN ALBERTA.[37]

1923	12,062,000	gallons
1924	14,708,000	"
1925	15,570,000	"
1926	21,189,000	"
1927	25,000,000	"
1928	40,900,000	"

have been 3,800,000 tons. This amount would have necessitated the mining of 10,000 tons per day throughout the whole year. It is obvious that the possibilities of bituminous sand development for gasoline manufacture are of an entirely different order from those for production of road materials. The quantities of material involved are sufficiently large to allow of mining and separating operations on a scale which will reduce unit costs to a minimum.[38]

The logical location for a refinery manufacturing gasoline from bituminous sands would be Edmonton and the natural market for the sale of its product would be the northern part of the province. The extent of this market can be gauged by the distribution of motor cars throughout Alberta. This distribution is shown by Table IV and the map of Fig. 2, showing the division of the province into the sub-areas used in compiling the table, namely, the provincial electoral districts. The northern portion of the province considered is roughly that part north of a line extending across it mid-

37Data supplied by the office of the Provincial Secretary for Alberta. The figures have been rounded off to thousands of gallons.

38As has been noted before, the cost of $5.65 per ton for separated bitumen is estimated on the basis of bituminous sand mining and separation on the scale of 1,000 tons per day for a 200-day season.

way between Edmonton and Calgary. Actually, it includes the electoral districts of Edson, Red Deer, Stettler, Ribstone and all districts to the north of these. The table shows that about 45% of the cars in Alberta are in this northern part. Consequently, about this proportion of the gasoline consumed in the province is sold there.

TABLE VI.—DISTRIBUTION OF POPULATION THROUGHOUT THE FEDERAL ELECTORAL DISTRICTS OF ALBERTA.

(The federal electoral districts are divided into two groups which correspond approximately with the northern and southern groups of provincial electoral districts used in Table IV. The population of the federal district of Red Deer has been divided between the northern and southern group in the ratio of 3:7 to effect the approximation.)

Northern Districts.	**1901**	**1906**	**1911**	**1916**	**1921**	**1926**
Athabaska	4,261	7,671	16,881	30,393	37,214	41,095
Battle River	9	4,906	21,263	30,187	36,737	37,215
Camrose	1,652	15,673	27,447	33,167	38,274	38,564
Edmonton East	5,553	15,673	19,803	33,997	36,263	40,017
Edmonton West	4,490	5,919	22,802	33,953	38,748	43,494
Red Deer (3/10)	1,954	5,425	8,183	8,776	10,595	11,008
Peace River	3,151	5.543	15,844	25,717	39,727	42,784
Vegreville	7,399	15,592	21,337	27,053	30,593	35,470
Wetaskiwin	13,042	21,932	26,554	31,035	34,785	38,949
Total	41,511	98,596	180,114	254,278	302,936	328,596
Southern Districts:						
Acadia	93	479	16,984	31,444	39,974	33,188
Bow River	1,559	5,520	18,076	20,520	34,323	33,776
Calgary East	5,143	18,261	30,039	34,575	38,076	40,328
Calgary West	2,901	5,780	25,894	36,608	40,122	41,064
Lethbridge	7,365	14,238	30,140	31,740	38,079	39,646
Macleod	6,654	22,608	30,131	33,091	33,826	36,872
Medicine Hat	3,237	7,056	23,823	33,710	36,395	28,444
Red Deer (7/10)	4,559	12,657	19,094	20,476	24,723	25,685
Total	31,511	86,599	194,181	242,164	285,518	279,003
Grand Total	73,022	185,195	374,295	496,442	588,454	607,599
Per cent. of Population in Northern Districts	57%	53%	48%	51%	51%	54%

The consumption of gasoline in Alberta is increasing rapidly as can be seen by the figures in Table V. It is reasonable to suppose that the increase will become more rapid in the northen part of the province. It has the larger population at the present time (Table VI) and with the growth of the Peace River district and the general trend toward northern development, it will receive the larger part of newcomers of the future. Main highway improvements, which are directly related to motor car operation and gasoline consumption, have so far been largely confined to the south. With similar attention to the northern part of the highway system there will be a greater number of cars owned per unit of population, greater use of them, and a still more rapidly expanding gasoline market in the north.

It would have taken 4,500 tons of bituminous sand per day throughout the year to have supplied the northern part of Alberta with gasoline in 1928. By 1930, the quantity will have increased to 6,000 tons per day. It cannot be assumed, of course, that a bituminous sand industry would have a monopoly in its home market. But on the other hand, there is no reason to consider that its market would be entirely confined to the area that has been discussed. At least, it can be said that there is ample scope for an industry of sufficient size to operate on an economical unit cost basis. Once it becomes possible to produce gasoline from bituminous sands profitably, and an industry is established, it should expand rapidly.

CHAPTER VI.

CONCLUSION.

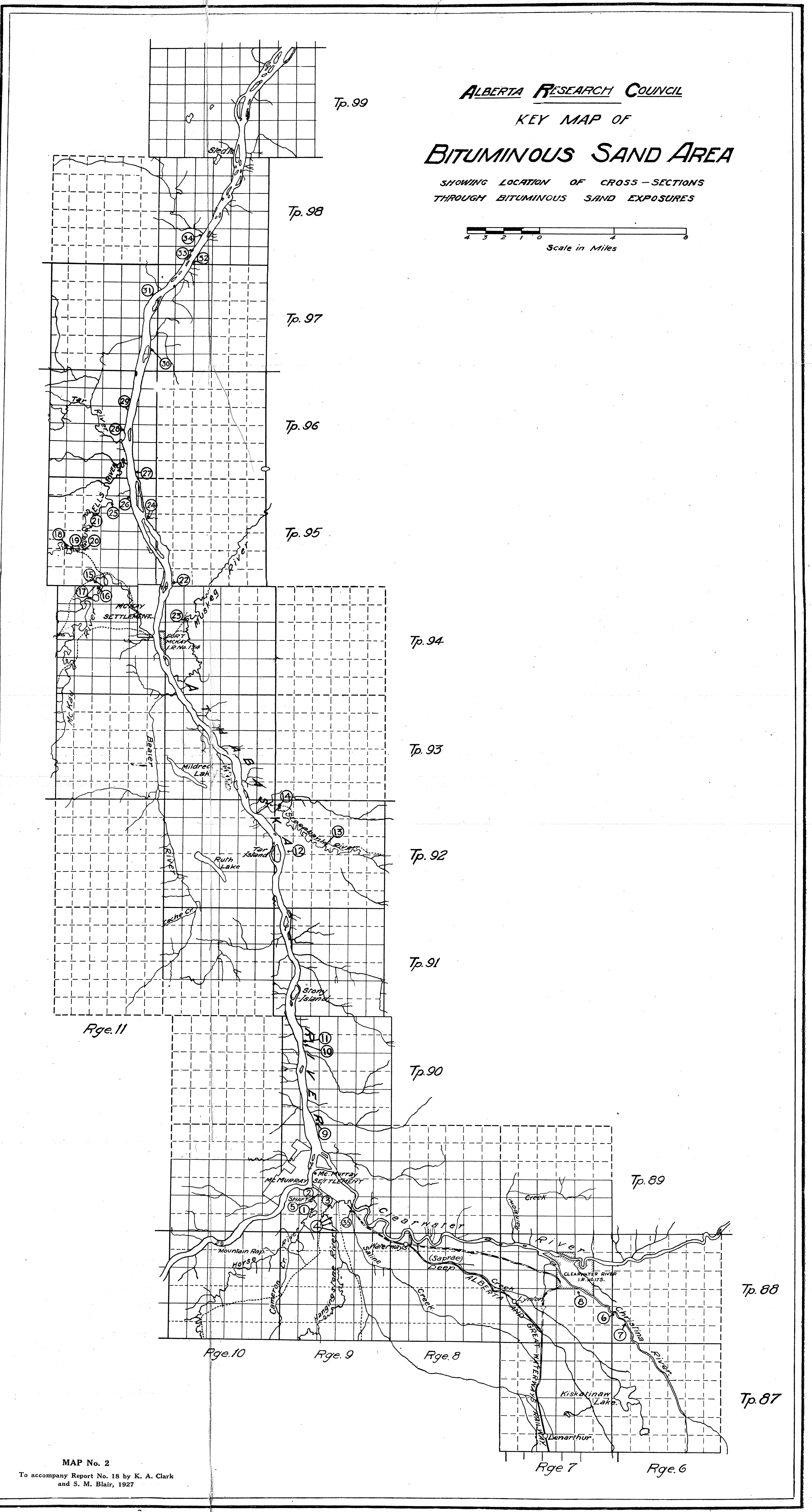
Road building developments in the west have always been thought of as holding the key to bituminous sand utilization. However, it is difficult to foresee how a large enough outlet for road materials can be found to provide the volume of business necessary for the economical and profitable mining and separation of bituminous sand. The main chance for such an outlet is for asphalt emulsion. This road material is likely to supersede to a large degree the road oils and asphalts that have been used in road construction and to be employed extensively in the building of the highways throughout the prairie provinces. The bituminous sands are a logical course of asphalt for manufacture of the emulsion for the Western Canadian market. This market may become sufficiently large to form a basis for development. A comparatively small industry for supplying it would be profitable in itself and would serve also as a convenient stepping stone toward the establishment of a broader and more extensive bituminous sand industry.

The use for bituminous sand that offers prospect of sufficient application to support an extensive industry is that for gasoline manufacture. It has been shown that the supplying of the present gasoline demand in the northern part of Alberta from the bituminous sands would necessitate the mining of 4,500 tons of the material per day throughout the year. It has also been shown that for the economical operation of a bituminous sand industry, there should be sufficient business for it to allow of a scale of development of 1,000 tons per day for at least 200 days of the year. Unit costs of mining particularly, and also of operation cannot be reduced to a value approaching the minimum unless a large volume of material is handled. There is difficulty in visualizing how 1,000 tons per day of bituminous sand could be disposed of by the sale of road material. The difficulty disappears if the bituminous sand can be disposed of by the manufacture and sale of gasoline. Consequently gasoline manufacture is the objective to be striven for. If it can be reached, the sort of industry that one would wish to see established on the great bituminous sand resources of the province would result.

Whether the manufacture of gasoline is feasible at the present time is a matter which must be left to the oil industry to decide. Technical difficulties do not stand in the way. The problems of mining bituminous sand and separating the oil from it are understood in a general way at least and no particular trouble should be encountered in working out the commercial details. The order of magnitude of mining and separation costs are known and are satisfactorily low. The cracking of the bitumen into gasoline has been tested by commercial firms and has been pronounced to be practical and productive of a particularly good quality of gasoline. A decision to undertake bituminous sand development would be made on the basis of economic rather than technical considerations. There is reason for believing that the economic situation is favorable. The preceding discussion points toward such a conclusion. And the fact that several substantial companies recently have given gasoline manufacture from the bituminous sands serious consideration is evidence that such a project is regarded by industry as being within the range of present possibilities. Right now, factors making for the success or failure of a bituminous sand undertaking are probably pretty evenly balanced. Each passing year should strengthen the factors favoring development. It is quite likely that by the time the details of a commercial scheme could be worked out and production established, there would no longer be any doubt about the economic soundness of a bituminous sand industry.

It is natural that the idea of bituminous sand development should be accepted with considerable hesitancy. It does not conform with the established order of things. The basis of the oil industry has always been the ever increasing supply of petroleum which has flowed from its wells. Such materials as bituminous sands have been regarded as the second line of defence against the time when oil supplies begin to fail. So far as the world situation is concerned, this time most certainly has not arrived. But it does exist in some sections of the world, and Western Canada is one of them. It has come about, not because petroleum supplies have diminished; instead the reason is that the demand for petroleum products has grown to large dimensions and the petroleum to supply it has not been found. Millions of dollars are being gambled on the chance of making the find. It is inevitable that this should be done. It is what has always been done under similar circumstances. And in the meantime the vast deposit of bituminous sand lies at the door almost unnoticed. The application to it of some foresight and part of the enterprise that is being displayed in other directions would have good chances of winnnig out against the lavish expenditures that are being thrown into the search for elusive oil pools. The bituminous sands would not provide the thrill of discovery nor the spectacle of the outpouring of sudden wealth in the way that gushing oil wells would do. Their development would be a straightforward, prosaic affair. But with a safe margin of profit, the enterprise would nevertheless be a satisfactory undertaking and is worthy of careful consideration.

The impression that the bituminous sands are buried away in the inaccessible and distant northland has been another factor standing in the way of their development. What truth there has been behind this impression is rapidly disappearing. Their inaccessibility was removed by the building of the Alberta and Great Waterways Railway, and their distance is being steadily diminished by the advance of settlement northward. It will not be long before the bituminous sands will be centrally located with respect to large population and extensive commercial activity. The Peace River district, which is developing into a great agricultural area, lies to the west of them; agricultural settlement is pushing nearer from the south every year; important mining activities are in the making in Northern Saskatchewan to the east; and fisheries and general trading activities are growing to a surprising extent northward to the Arctic. The whole northland is being invaded. Aeroplanes are crossing it in all directions in the interests of exploration and prospecting. Branch railways are being built into rich mineral areas already discovered and main lines are being considered in preparation for the general development that is anticipated. All indications point to a great forward movement which will bring the expanse of country in which the bituminous sands lie within the range of industrial activity.



MAP No. 2
To accompany Report No. 18 by K. A. Clark and S. M. Blair, 1927

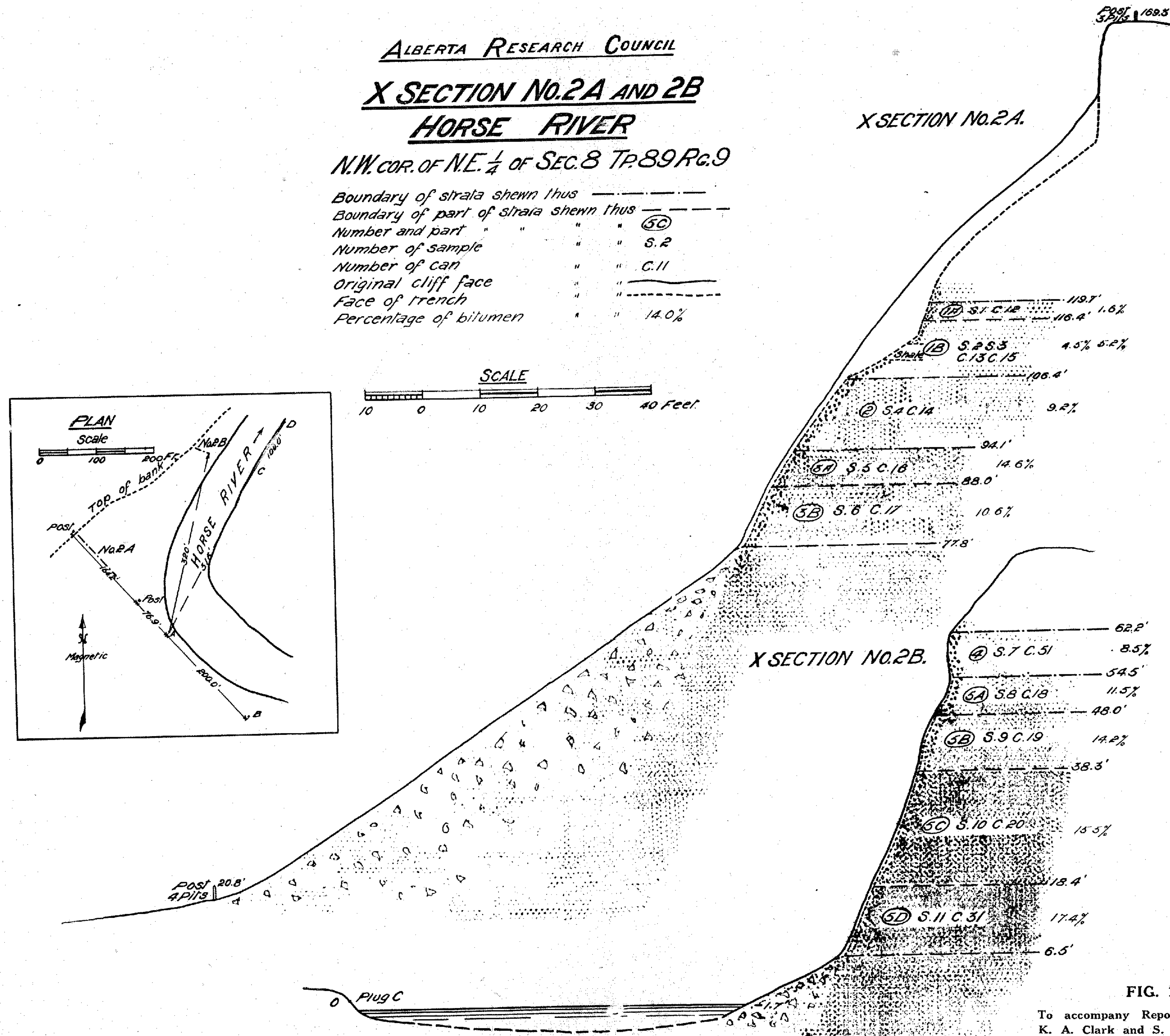


FIG. 1

To accompany Report No. 18 by K. A. Clark and S. M. Blair, 1927

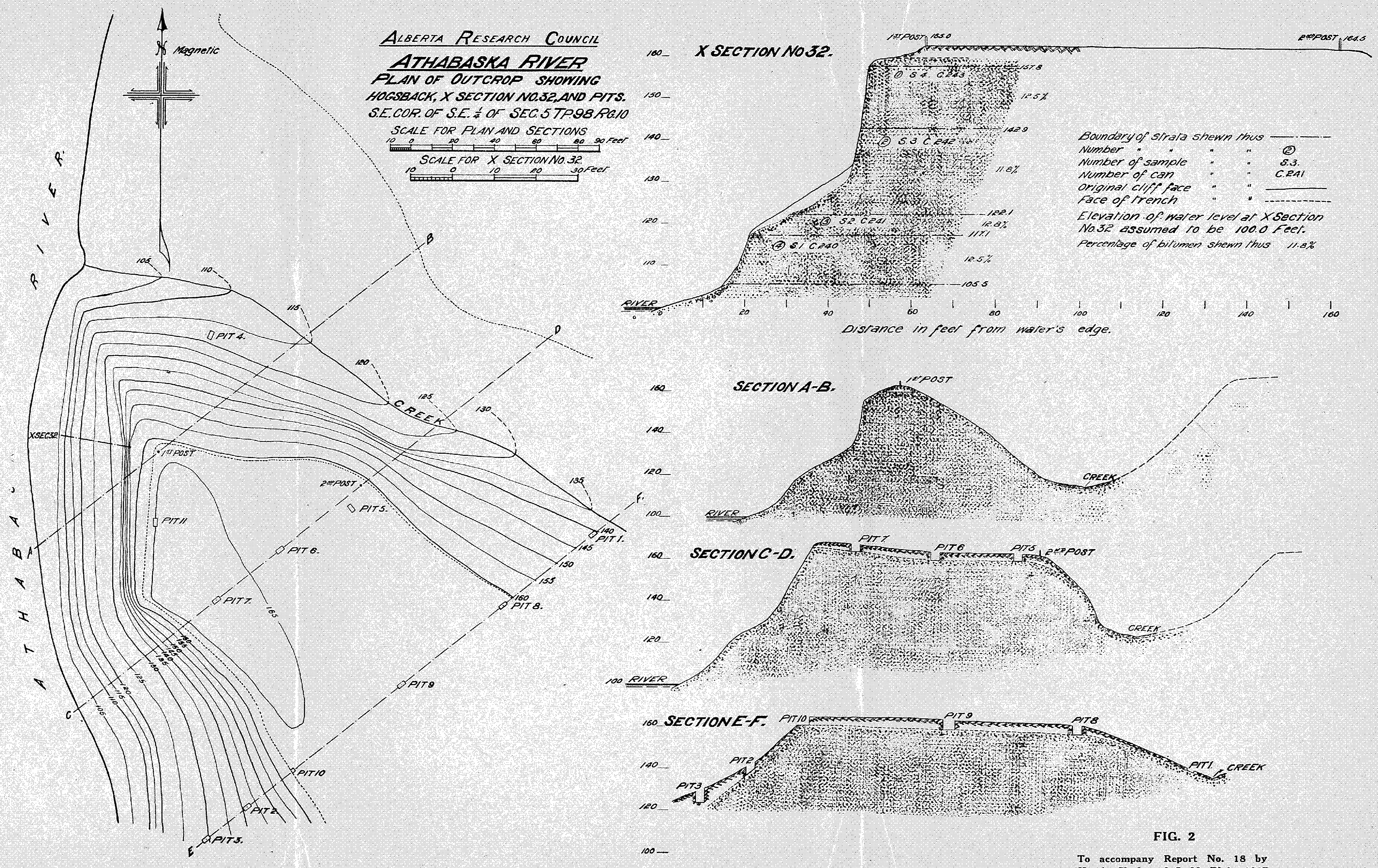
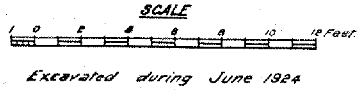


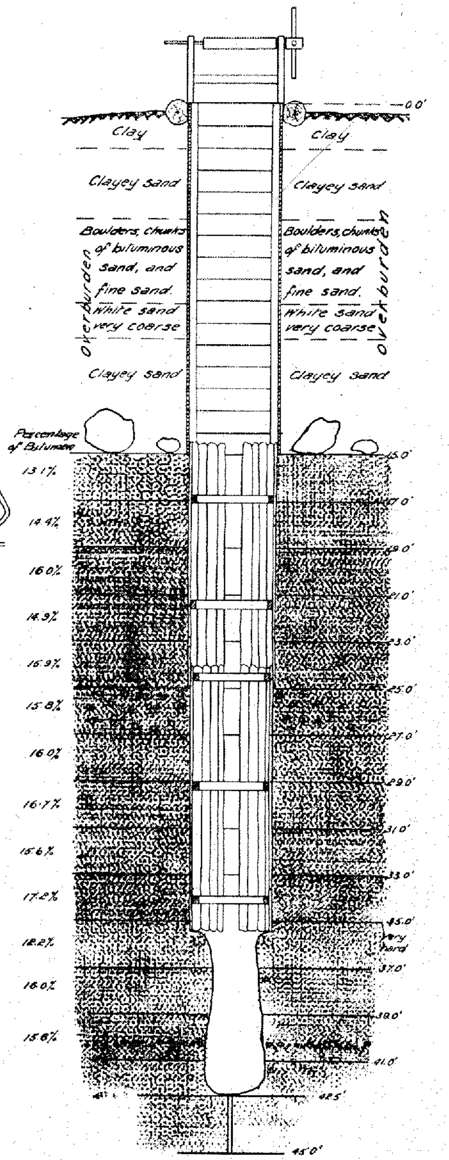
FIG. 2

To accompany Report No. 18 by K. A. Clark and S. M. Blair, 1927

Alberta Research Council

X SECTION OF SHAFT HORSE RIVER





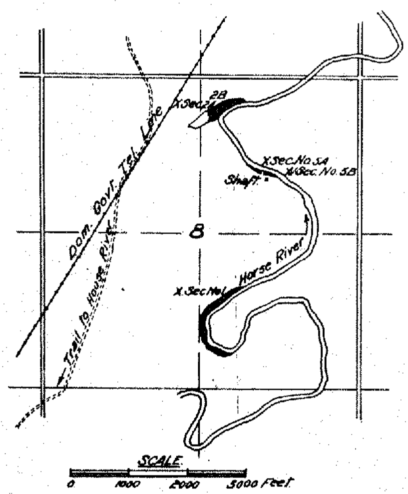


FIG. 3

To accompany Report No. 18 by K. A. Clark and S. M. Blair, 1927